A forensic taphonomic study into the differential decomposition rates and patterns of bodies subjected to varying degrees of burns

by

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Declaration

I declare that this Dissertation is my own, unaided work. It is being submitted for the degree of Master of Science in Medicine at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

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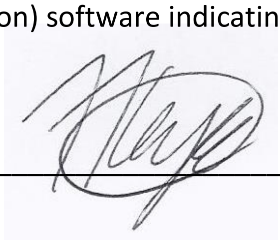
Signature:  Date: 07 September 2016

Abstract

Despite the high number of worldwide fatal burn cases investigated by forensic experts, there is a lack of literature on the effects of burning on soft tissue decomposition. The objectives of this study tested the reliability of the charred body scale (CBS), developed a TBS scoring system for specific burn levels, compared burned and unburned body decomposition rates and patterns, compared summer and winter decomposition rates, and determined if body region or CGS level effects individual body region decomposition. Six *Sus scrofa domesticus* carcasses were burned to different Crow-Glassman Scale (CGS) levels and left to decompose - two in winter (control, CGS level 2) and four in summer (unburned control, CGS level 1, CGS level 2, CGS level 3). Decomposition patterns, charred body scale (CBS) scores and unique burn level scores were recorded at 50 accumulated degree-days (ADD) intervals. A unique TBS method was developed for each CGS level. This study established that the CBS system is not a reliable method for scoring burned remains. Burning alters normal decomposition processes, including the abnormal bloating of the CGS level 1 pig and the absence of visible bloat in all CGS level 2 pigs. All CGS level pigs exhibited abnormal decomposition patterns. There is a significant difference ($p=0.0002$) in the decomposition rates of burned remains. The CGS level 1 pig decomposed furthest followed by the CGS level 3 pig, then CGS level 2 pig and finally the unburned control pig. Burning results in the earlier onset of decomposition stages in summer but significantly slows the decomposition rate in winter ($p<0.0001$). There is a significant interaction between CGS level and body region on the decomposition rate in winter ($p<0.0001$) and summer ($p=0.0228$). This research is novel in South Africa and internationally. These preliminary findings will assist forensic experts to better understand the context of burn cases and therefore postmortem events can be more accurately reconstructed.

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Chapter 1: Introduction

In 2004 the World Health Organization's (WHO) Global Burden Disease Report (2004) stated that severe burns requiring medical attention listed as the fourth highest incidence of all injuries; preceded only by road traffic accidents, falls, and interpersonal violence respectively. Worldwide, nearly 11 million people were injured as a result of severe burns in 2004. It was also reported that fatal burns and fires cause 300,000 deaths annually throughout the world. Ninety percent of global burn fatalities occur in lower-middle to low income countries (Peck 2011).

The world-wide burn mortality rate is an average of 5.0 per 100,000 persons annually. African nations experience a higher fire-related mortality rate of 6.1 per 100,000 persons (World Health Organization 2002). Some regions in South Africa experience even higher fire-related mortality rates than the African and Global average. The city of Cape Town has a burn mortality rate of 7.9 per 100,000 persons (Van Niekerk, Laubscher & Laflamme 2009). Infants in Africa have an alarmingly higher incidence of fire-related burns, an incidence that is three times greater than the world average for their age group (Hyder *et al.* 2004).

The prevalence of severe and fatal burns in South Africa is attributed to extensive use of open fires and kerosene stoves as a source for cooking and heating in the many low socioeconomic regions. The energy crisis throughout Africa contributes to the use of cheaper, flammable and hazardous heat sources (Albertyn, Bickler & Rode 2006; Van Niekerk, Reimers & Laflamme 2006; Legros *et al.* 2009; Van Niekerk *et al.* 2009).

Past research into fatal burns in South Africa have only been performed in the Western Cape and Mpumalanga provinces. These studies have reported that most are accidental or non-intentional (Van Niekerk *et al.* 2009; Blom, Van Niekerk & Laflamme 2011). A study in the Mpumalanga province found that 68.4% fatal burn deaths in the region were non-intentional, 9.9% were homicide-related, while 3.7% were suicide-related deaths (Blom *et al.* 2011). These findings are consistent with international studies (Fanton, Jdeed, & Malicier 2006; Büyük & Koçak 2009). A study in Turkey noted that 70% of fire-related deaths were accidental and 10% resulted from deliberate intervention (meaning non-accidental deaths initiated by the deliberate lighting of fires) (Büyük & Koçak 2009). A study in France found that 52% of fire-related deaths were accidental, 31% were criminal and 16% were suicidal (Fanton *et al.* 2006).

In France, accidental fire-related deaths most commonly occur in homes or residences and in vehicles. In circumstances where bodies are found in unfamiliar outdoor locations, the cause of death has always been homicide (Fanton *et al.* 2006; Tümer *et al.* 2012). In South Africa, bodies are often found in unfamiliar outdoor locations, especially in the large grasslands (commonly termed veldt).

These regions are not only used as convenient areas to hide bodies but are also used by the homeless for shelter (Myburgh et al. 2013). These veldts get very dry and commonly experience bush/veldt fires. Bodies that are found in the veldt often exhibit signs of burning and charring, either due to natural veldt fires or criminal postmortem (after death) burning.

Postmortem burning is often a means of covering-up or destroying evidence of a homicide (Fanton *et al.* 2006; Büyük & Koçak 2009; Tümer *et al.* 2012). Postmortem burns tend to exhibit charring over at least 80% of the body surface depending on the accelerant/flammable material used (80-85% if nylon is used, 80-95% if kerosene is used, 90-100% if gasoline is used as an accelerant) (Tümer *et al.* 2012). Criminal burning can be distinguished from suicidal burning because self-immolation burns typically exhibit charring, mostly on the head and trunk regions and never on the soles of the feet (Fanton *et al.* 2006).

Fire-related deaths (accidental, homicidal and suicidal) are all considered 'unnatural' or 'other than natural' deaths (National Health Act no. 61 of 2003). These deaths are investigated by medico-legal investigators (forensic scientists) and are received by the Forensic Pathology Service Medico-legal Mortuaries in South Africa. Forensic science is the application of multidisciplinary scientific fields to the medicolegal system, in the collection and analysis of evidence (İşcan 1988). As such a number of forensic fields can assist in the investigation of fire-related deaths, including forensic anthropologists and forensic taphonomists (Schmidt & Symes 2008).

Forensic anthropology is the multidisciplinary field that combines physical anthropology, archaeology, taphonomy and other fields such as forensic odontology and pathology. The goals of forensic anthropology include: providing a biological profile (age, sex, ancestry, stature) of forensic skeletal remains, personal identification of forensic skeletal remains, performing outdoor crime scene analysis, determining postmortem intervals (time since death), and skeletal trauma analysis (İşcan & Steyn 2013).

Forensic taphonomy is the scientific field focused on the reconstruction of circumstances before death (antemortem), at the time of death (perimortem), and after death (postmortem). Some taphonomic influences studied include: animal scavenging, weathering patterns, water processes, temperature, environment and fire trauma. Forensic taphonomy is a field often used by paleontologists, archaeologists and, more recently, forensic anthropologists (Haglund & Sorg 1996; Haglund & Sorg 2002).

Burn cases are often referred to forensic anthropologists since tissue modification by charring frequently presents with bone trauma. The identity of these victims may also be obscured. Forensic anthropologists are able to assist in the identification process and trauma analysis – analysis of both bone trauma and soft tissue modifications (Schmidt & Symes 2008).

The high incidence of fatal burn cases referred to forensic anthropologists for skeletal and taphonomic analysis in South Africa necessitates further research into the effects of thermal alteration on soft tissues and decomposition.

1.1 Aims and objectives

The aims of this study were:

1. To determine if bodies with different levels of burning have different rates and patterns of decomposition.
2. To determine the effect of seasonal differences on the decomposition of burned remains.

The objectives of this study were:

1. To determine the reliability of charred body scales on analyzing the decomposition of burned remains.
2. To describe the decomposition patterns of unburned and burned bodies (CGS level 1, CGS level 2 and CGS level 3).
3. To compare the rate of decomposition between unburned and burned bodies (CGS level 1, CGS level 2 and CGS level 3).
4. To compare the effect of seasons (summer and winter) on the rate of decomposition between unburned and burned bodies at an CGS level 2.
5. To determine if body region or CGS level determines rate of decomposition.

1.2 Research question

How are soft tissue decomposition rates and patterns altered by varying levels of burns?

Chapter 2: Literature Review

2.1 Decomposition processes

The decomposition of a human body is initiated by the cessation of all bodily vital activities and subsequent cellular death. Cellular death is caused by the termination of metabolic functions, primarily aerobic respiration. The destructive processes of decay are caused by the breakdown of organic matter which occurs through biochemical reactions and bacterial activity. The biochemical reactions of decay include autolysis and putrefaction (Saukko & Knight 2004; Fitzgerald & Oxenham 2009; Michaud & Moreau 2011).

Autolysis is caused by the digestion of cells by their own enzymes (via release of intracellular enzymes) leading to the softening and liquefaction of tissues. The decomposition processes associated with autolysis are algor mortis, livor mortis and rigor mortis. Algor mortis is the process of the cooling of the body temperature due to the ceasing of metabolic functions. Livor mortis (also termed hypostasis) is the gravitational pooling of the blood in the capillaries. This pooling of blood is visible through the skin as bluish red pigmentation with variability between pink to blue discoloration depending on the level of oxygenation of blood at the time of death (Knight 1997; Saukko & Knight 2004; Shkrum & Ramsay 2007). Rigor mortis is the process of postmortem muscle contraction as a result of the sarcoplasmic reticulum losing its integrity via autolysis. This leads to the release of calcium stores which inundate the sarcomeres leading to the locking of the actin-myosin filaments. The reversal of this process is prevented by the halt in ATP synthesis (Kobayashi *et al.* 1996; Knight 1997; Saukko & Knight 2004; Shkrum & Ramsay 2007).

Putrefaction is the breakdown of cell proteins leading to tissue and organ liquefaction and subsequent transformation into a gaseous form. This process is driven by haematogenous spread (the spread of intestinal bacteria and microorganisms through the blood of the vascular system). Putrefaction is initially exhibited as the blue-green discolouration of the abdominal wall and marbling (the branching discolouration pattern in the skin outlining the pigment-stained venous system). However, it must be noted that putrefaction and decomposition processes in new-born babies are delayed due to the absence of intestinal bacteria (Saukko & Knight 2004; Shkrum & Ramsay 2007).

2.2 Decomposition stages

The decomposition process can be separated into a number of subjective stages based on observed criteria (Michaud & Moreau 2011). The number and names of stages vary depending on the literature and author. The number of stages can be combined into as few as three stages (Parks 2011) or up to as many as 21 stages and sub-stages (Adlam & Simmons 2007; Fitzgerald & Oxenham 2009). However, the general criteria for all these varying stages are the same (Rodriguez & Bass 1983; Galloway *et al.* 1989; Michaud & Moreau 2011). The five generally accepted stages of decomposition are: early stage, bloat stage, active decay stage, advanced decay stage and dry stage (Michaud & Moreau 2011).

2.2.1 Early stage

The early stage of decomposition begins at time of death and ends at the onset of bloating (Rodriguez & Bass 1983; Michaud & Moreau 2011). This stage includes livor mortis, abdominal discolouration, marbling of the skin, skin slippage and hair loss (Galloway *et al.* 1989). These processes are common in human and pig model decomposition studies.

Abdominal discolouration is usually noted as a dark blue-green colour in the lower abdominal quadrants, starting from the right and spreading to the left. This region is primarily affected as a result of the caecum's superficial location in relation to the skin. The caecum has a high anaerobic bacterial content (such as *Clostridium welchii*). Haemolysis and hydrogen sulphide gas production by anaerobic bacterial activity cause the breakdown and spread of sulphaehaemoglobin (a by-product and pigment of haemoglobin breakdown) and other pigments. These pigments lead to localised skin discolouration at areas of lividity to turn blue-green, purple or black (Saukko & Knight 2004; Shkrum & Ramsay 2007).

The anaerobic bacteria originating in the intestines spread easily through liquid blood and hence colonize the venous system readily. Pigmentation from haemolytic activity causes the staining of vessel walls and are exhibited as a branching outline of greenish discolouration most commonly viewed in the abdomen, chest and thighs (Saukko & Knight 2004; Shkrum & Ramsay 2007).

Skin slippage is common in human and animal decomposition and is caused by the loss of anatomic integrity of the skin and tissues. Skin may peel off in localised areas and cutaneous blisters that are gas- or fluid-filled may occur simultaneously. The skin of the hands and feet, in humans, can also loosen and remove as a single 'glove' in a process termed 'degloving'. Similarly, hair and nail loss occurs as the attachments loosen. Nail beds become detached from the fingers and scalp hair follicles often loosen resulting in the hair detaching from the skin as a mass (Mann, Bass & Meadows 1990; Shkrum & Ramsay 2007).

2.2.2 Bloat stage

The bloat stage of decomposition occurs from the onset of bloating until deflation of the abdomen. This bloating is caused by the accumulation of gases caused by bacterial activity during putrefaction. Gases produced include hydrogen sulphide, ammonia, methane and carbon dioxide. These gases accumulate in the intestines and permeate into surrounding organs leading to abdominal distention. These gases also permeate into the soft tissues surrounding the gastro-intestinal tract leading to the localized distention of the genital, facial and anal regions (Shkrum & Ramsay 2007). Key characteristics of this stage are abdomen distention, neck distention, protrusion of the anus, raised limbs, green discolouration of the abdomen and brown discolouration of the fingers, nose and ears (Rodriguez & Bass 1983; Galloway *et al.* 1989; Shkrum & Ramsay 2007; Michaud & Moreau 2011).

2.2.3 Active decay stage

Abdominal deflation, caused by the escape of accumulated gases, marks the beginning of the active decay stage of decomposition. The escape of accumulated gases is assisted by the presence and feeding action of maggots (Michaud & Moreau 2011). The key characteristics of this stage include the presence of large maggot masses on the body, caving in of the abdominal cavity and moist decomposition with partial bone exposure (Rodriguez & Bass 1983; Galloway *et al.* 1989; Michaud & Moreau 2011). The moist decomposition is aided by proteolytic enzymes secreted by the maggots (Saukko & Knight 2004).

2.2.4 Advanced decay stage

The advanced decay stage of decomposition begins with the sudden decrease in maggot numbers on the body as they leave to pupate (Michaud & Moreau 2011) and an increase in beetle activity (such as Dermestidae (skin beetles), and Cleridae (checked beetles)) (Parks 2011). An increase in the number of beetles is seen at this stage since these beetles feed on dried skin, hair, and tendons - which are found in ample supply on advanced decomposed bodies (Kolver 2009). This stage includes the following variable criteria (which may be inclusive or exclusive of one another): wet decomposition or mummification with the retention of some internal organs, mummification and loss of internal organs due to autolysis or insect feeding, wet decomposition or mummification with bone exposure (less than half the skeleton is exposed) and/or adipocere formation.

Mummification is a variation of decomposition whereby liquefying putrefaction processes are replaced by the skin generally being altered into a brown-black leathery tissue. This transformation is caused by a combination of tissue desiccation and the inhibition of bacterial activity. For mummification to occur it is essential that the environment be dry. Mummification is not isolated to hot areas but is also possible in cold conditions and in areas where snow occurs; as long as the tissues remain dry (Ambach, Tributsch & Ambach 1992; Saukko & Knight 2004). Mummification can be localized, partial or extended over the entire body (Saukko & Knight 2004; Shkrum & Ramsay 2007).

Adipocere is a waxy, greasy, clay-like substance with a chalky-white appearance that is formed by the action of enzymes released by anaerobic bacteria or the action of endogenous lipase on subcutaneous fat. Triglyceride hydrolysis causes neutral or storage fats to liquefy and penetrate surrounding tissues and viscera. Bacterial enzymes convert unsaturated fatty acids into saturated fatty acids (particularly palmitic and stearic acid) (Shkrum & Ramsay 2007). These fatty acids have a higher melting point than the surrounding temperatures causing crystallization of the fatty acids. The process of adipocere formation is termed saponification (Gill-King 1996). Adipocere is more likely to be formed in obese and female individuals due to their higher body fat content (Fiedler & Graw 2003; Shkrum & Ramsay 2007). In addition, certain environmental conditions are necessary for adipocere formation. Moisture is a necessary component for the hydrolysis process and hence bodies immersed in water or those in damp graves will typically exhibit adipocere formation. However, a number of cases that have been stored in dry concealed/sealed areas have exhibited adipocere. These cases have led to the hypothesis that water naturally stored within the body tissues may be able to provide sufficient water quantities for hydrolysis to occur and result in adipocere formation (Rodriguez & Bass 1983; Fiedler & Graw 2003; Forbes *et al.* 2004; Saukko & Knight 2004; Shkrum & Ramsay 2007; Galloway *et al.* 1989; Michaud & Moreau 2011).

2.2.5 Dry stage

The dry stage of decomposition is the stage when the majority of human remains still present are the skeletal elements. This stage includes the following criteria: dry skin, hair and bones, bones with greasy substances and decomposed tissue, bones with desiccated or mummified tissue covering less than half the body, mostly dry bone with some grease, or dry bone only (Rodriguez & Bass 1983; Galloway *et al.* 1989; Michaud & Moreau 2011).

2.3 Variables that affect decomposition

Very few studies have been done in South Africa on variables that effect decomposition. Therefore, a general discussion of variables that have been studied internationally is necessary. A number of variables have a significant effect on the decomposition rate and process. Every decomposition case presents in a unique context, each with a different level of exposure to factors that all play a role in the rate and pattern of decomposition (Mann *et al.* 1990). The primary process of soft tissue autolysis is aided by bacteria and insects in the decay of organic material. These are further aided or hindered, to varying degrees, by a number of environmental factors. Table 2.1 presents the variables studied by Mann *et al.* (1990) on human bodies in Tennessee, United States. Each of the variables were rated on a five-point scale listing those with the greatest influence (5 points) to those with the least influence (1 point). The variables listed are not inclusive of all variables that play a part in decomposition but are representative of the numerous contextual factors that can play a role in decomposition. It was found that temperature, arthropod colonization and burial have the greatest influence on decay rate, followed by carnivore scavenging, trauma (peri- and postmortem) and humidity/aridity.

2.3.1 Temperature

The variable that has the most significant influence in decomposition is temperature (Michaud & Moreau 2011). Temperature directly affects the biological, biochemical, and enzymatic reactions that cause the decomposition of soft tissue. As such, contrasting seasons and climates will exhibit differential rates of decomposition (such as the summer season versus the winter season or arid climates versus tundra climates) (Galloway *et al.* 1989).

Table 2.1: Rating of variables that affect decay rates of human bodies (taken from Mann, Bass & Meadows 1990)

Variable	Effect of Decay Rate*
Temperature	5
Access by insects	5
Burial and depth	5
Carnivores/rodents	4
Trauma (penetrating/crushing)	4
Humidity/aridity	4
Rainfall	3
Body size and weight	3
Embalming	3
Clothing	2
Surface placed on	1
*Subjective criteria rating based on a five-point scale. 5 being the most influential.	

A number of studies have found that decomposition rates in the summer season are rapid. Higher temperatures lead to increased rates of putrefaction, carrion colonization by arthropods, soft tissue dehydration, and humidity or aridity. Bodies discovered in months of high average temperatures tend to be in more advanced stages of decomposition (Rodriguez & Bass 1983; Galloway *et al.* 1989; Mann *et al.* 1990; Shean, Messinger & Papworth 1993; Komar 1998; Weitzel 2005; Sharonowski, Walker & Anderson 2008).

Similar studies have found that the lower temperatures of winter decrease the rate of decomposition (Sharanowski, Walker & Anderson 2008). Cold temperatures cause a reduction or complete halting of biochemical and bacterial processes. Arthropod activity is also affected with larval activity being restricted to the day-time (Galloway *et al.* 1989) or extremely low temperatures killing maggots (Mann *et al.* 1990). The dehydration of soft tissues in regions where snowfall and rainfall occur in winter (Galloway *et al.* 1989) can lead to maintaining bodies within the early stages of decomposition. Low temperatures can even preserve bodies with no changes other than skin discolouration to orange or black (Mann et al. 1990).

These findings were corroborated by studies that were performed in different areas such as Canada (Komar 1998; Weitzel 2005; Sharanowski *et al.* 2008; Michaud & Moreau 2011) and the United States (Rodriguez & Bass 1983; Galloway *et al.* 1989; Mann *et al.* 1990; Shean *et al.* 1993), and with different models such as human bodies (Rodriguez & Bass 1983; Galloway *et al.* 1989; Mann *et al.* 1990; Komar 1998) and pig carcasses (Shean *et al.* 1993; Weitzel 2005; Sharanowski *et al.* 2008; Michaud & Moreau 2011). These studies all agree that temperature plays a large role in decomposition rate.

2.3.2 Environment

The environment in which a body decomposes also has an effect on decomposition as it either promotes or inhibits the numerous variables that assist the decomposition process (i.e. temperature, carrion colonization, predators, humidity, etc.). Four environments that have been extensively studied include outdoor, indoor, burial and aquatic environments (Weitzel 2005; Heaton e*t al.* 2010; Anderson 2011).

2.3.2a Outdoor environments

A study by Anderson (2011) performed in Canada using pig models found that outdoor environments tend to allow for increased rates of decomposition (Anderson 2011). This is due to greater exposure to variables. Bodies that decompose outdoors tend to be found in the advanced stages of decomposition. The outdoor environment exposes decomposing bodies to sunlight, rapid colonization by insects, predation, and greater temperature extremes. A study in the United States, using human models, found the high outdoor temperatures of arid environments can result in the mummification of human remains (Galloway *et al.* 1989). However, in outdoor cases where there is exposure to rainfall, the rate of decomposition is decreased or halted due to the prevention of tissue dehydration (Galloway *et al.* 1989). A study in the United States on human models found rainfall further affects decomposition by affecting the insect colonization and activity on an exposed body. While arthropod colonization is halted by rainfall, internal maggot activity is not impeded (Mann *et al.* 1990).

Bodies exposed to moisture, such as near a river or constant precipitation, will have an altered decomposition pattern. The presence of moisture will cause the formation of adipocere which would preserve the body (Rodriguez & Bass 1983; Galloway *et al.* 1989; Fiedler & Graw 2003; Forbes *et al.* 2004; Saukko & Knight 2004; Shkrum & Ramsay 2007; Michaud & Moreau 2011).

2.3.2b Indoor environments

Indoor environments exhibit decomposition cases with a slower rate of decomposition (compared to outdoor environs). This is primarily due to protection from carrion colonization (Anderson 2011), as well as protection from direct sunlight. As such, bodies decomposing in well closed structures that limit the entry of insects would be discovered in the earlier stages of decomposition when compared to bodies decomposing in outdoor environments during the same period. Indoor environments can exhibit deviations in the typical pattern of decomposition such as the prevention of mummification and the elongation of the bloating period (Galloway *et al.* 1989).

These studies in Canada (Anderson 2011) and the United States using human bodies (Galloway *et al.* 1989) and pig carcases (Anderson 2011) agree that indoor environments present cases with slowed decomposition rates.

2.3.2c Burials

Studies in the USA on human decomposition have determined that the rate of decomposition of buried bodies have been observed to be slower than those exposed on the surface. Burial delays the decomposition process as it protects the body from, or limits, the variables that increase decomposition rates (Galloway *et al.* 1989, Mann *et al.* 1990). Bodies buried directly in soil exhibit fungal growth, moist decomposition and the absence of bone bleaching and exfoliation (Galloway *et al.* 1989). The depth of burial will also affect the rate of decomposition with the rate slowing the deeper a body is buried. In addition, bodies wrapped in plastic decay slower than bodies that have not been wrapped in plastic (Mann *et al.* 1990). Other burial-linked factors that affect decomposition rates have been studied on pig models in Canada, such as soil temperature and soil pH (Weitzel 2005). Haslam and Tibbet (2009) performed a study in the UK using sheep soft tissues and established that the more acidic the soil, the faster the decomposition of skeletal muscle tissue. Thus the rates of decomposition in bodies that are buried in Podsol (acidic soil) are three times that of bodies buried in Rendzina (alkaline soil).

2.3.2d Aquatic environments

A study by Heaton e*t al.* (2010) on human bodies discovered in UK waterways found that aquatic environments present a different set of variables (compared to terrestrial environments) which have the potential to affect decomposition. These variables include currents, tides, the level of dissolved oxygen, salinity, water acidity, debris interactions, water depth and pressure, water temperature, and the different species and behaviours of aquatic arthropods and scavengers (Heaton e*t al.* 2010). Although aquatic variables differ from terrestrial variables the patterns of aquatic decomposition do not deviate too drastically from terrestrial decomposition (Heaton e*t al.* 2010). The typical signs of decay, bloating, hair loss and carrion colonization, still occur (Mann *et al.* 1990). However, the rate of decomposition is affected by the submersion of bodies in water. The rate of decomposition decreases when submerged (Heaton e*t al.* 2010). Water temperature is more stable than the ambient temperature of air; it is an ever present, vital factor in aquatic decomposition. Warm water temperatures result in bodies resurfacing more rapidly and subsequent exposure to direct sunlight thus resulting in increased decay rates. Cold water temperatures lead to increased periods of submersion, increased depth levels and pressure as well as decreased water movement; all of which result in decreased decomposition rates (Heaton e*t al.* 2010).

2.3.3 Arthropod colonization

A UK study stated that the effects of insect colonization of human bodies play a direct role on the rate and level of soft tissue destruction in the decomposition process (Simmons, Adlam & Moffatt 2010). Decomposing bodies (carrion) provide a rich source of nutrients for arthropods and a diversity of various fauna. Some examples of carrion colonizers include Calliphoridae (blow flies), Sarcophagidae (flesh flies), Dermestidae (skin beetles), and Cleridae (checked beetles) (Kolver 2009). Carrion is favourable for insect egg deposition and predation by other fauna attracted to decaying matter. An increase in colonization leads to an increase in decomposition rate and biomass removal as maggots actively feed on the necrotic and putrefied soft tissues (Anderson 2011). A human decomposition study in the United States determined that environments that protect bodies against insect colonization, such as sealed rooms, refrigerators, or bags, cause decomposing bodies to be discovered in the earlier stages of decomposition. Therefore, bodies that cannot be colonized by insects decompose at a slower rate (Mann *et al.* 1990). The study of insect succession patterns is an invaluable method used in the estimation of postmortem intervals due to its close association to the progression of body decomposition (Voss, Spafford & Dadour 2009).

2.3.4 Clothing

A South African study and a Polish study, both using pig models, found that the presence of clothing or material wrappings, in isolation, have been found to have a minimal effect on decomposition rates (Kelly, van der Linde & Anderson 2009; Matuszewski *et al.* 2014). Similarly, a Malaysian study using rabbits, found the type of clothing or the fabric it is made from, does not have any significant effect on decomposition rates (Teo *et al.* 2013).

Clothing does however have an effect on decomposition when combined with the presence of arthropod colonization. Clothing has been found to increase the decomposition rates of bodies exposed on the ground as it protects maggots, allows for larger maggot masses and maintains soft tissue moisture retention (Mann *et al.* 1990; Kelly *et al.* 2009; Teo *et al.* 2013). Conversely, in burial cases, clothing delays decomposition since it protects soft tissues from direct exposure to soil and soil dwelling arthropods (Teo *et al.* 2013).

2.3.5 Sunlight versus shade

The rate of decomposition is different between environments that are in direct sunlight and those that are in the shade. Shean *et al.* (1993) noted that pig models exposed to direct sunlight, in the USA, decomposed more rapidly than those in the shade, in addition, indicated shorted periods of arthropod colonization. Sharanowski *et al.* (2008) studied this phenomenon in more depth, using pigs in Canada, and deduced that the rates of decomposition differed between the two only in spring when ambient temperatures were significantly different. In the other months there was no significant difference in the ambient temperatures between the shaded and sun-lit areas and hence no difference in the decomposition rates. Sharanowski *et al.* (2008) also noted that in the spring and fall (autumn) months, carrion in sun exposed environments attracted a greater variety of arthropod species and a greater number of each species compared to shaded carrion. This was confirmed by Aballay, Domínguez and Campón (2012) who established that fly abundance was greater at sunlit pig carrion than shaded pig carrion, in Argentina. The significant temperature differences and greater numbers of insects and species contribute to the increased decomposition rates in sun exposed carrion.

2.3.6 Scavenging

Carnivores and scavenger activity also affects the decomposition process (Galloway *et al.* 1989). Various vertebrates such as dogs, rodents, leopards, lions, birds and water predators all feed on carcasses (Pickering & Carlson 2004; Myburgh 2010). Larger carnivores and scavengers, such as dogs, have a greater influence on decay rates than smaller mammals (Haglund 1996). Evidence of predation in indoor environments is common as house pets (dogs and cats) are known to feed on a deceased owner (Rothschild & Schneider 1997; Tsokos & Schultz 1999). The majority of indoor cases that exhibit postmortem trauma are due to rodent activity (Tsokos *et al.* 1999). Disarticulation, ingestion of soft tissues and scattering of remains all increase the rate of decomposition as they increase the number of accessible areas for insect colonization and exposure to the elements (particularly in outdoor environments) (Myburgh 2010). However, predation of colonizing insects on decomposing bodies causes a decrease in the decomposition rate.

Scavenging of bodies in aquatic environments is common. Fish, crabs and turtles often feed on submerged bodies and cause a variety of trauma from small slits in the soft tissues to massive crushing injuries of bones (Haglund & Sorg 1996). No research has been published on the effects of aquatic scavenging on decomposition rates.

2.3.7 Trauma

Smith (2014) performed a study on penetrating trauma on pigs, in the USA, and determined that trauma is a variable that can play a role in decomposition patterns. Decomposition was observed to begin and proceed from the face in cases with no trauma. In cases with penetrating sharp-force trauma decomposition was observed to begin and proceed from the site of the wound(s). The reasoning provided for this difference was that penetrating trauma increased arthropod access into the body. In cases with non-penetrating sharp-force trauma decomposition begins simultaneously at the face and site of the wound (Smith 2014).

Resultant wounds from trauma (blunt force trauma, ballistic trauma – gunshot wounds – and sharp force trauma) act as access points for arthropod colonization and has previously been thought to contribute to an increase in decomposition rates (Mann *et al.* 1990; Myburgh 2010). However, recent studies on pigs in the UK have determined that penetrating trauma has no significant effect on decomposition rates, particularly when discussing time to skeletonization, weight loss and total body score assignment (Cross *et al.* 2010; Simmons *et al.* 2010; Smith 2014).

Smith (2014) observed that larger, penetrating wounds are favourable oviposition sites over natural orifices for Diptera. In cases with smaller wounds (such as small non-penetrating wounds or small gunshot wounds) natural orifices are favoured as oviposition sites (Cross *et al.* 2010; Smith 2014). Therefore, wounds do not increase the number of insect colonisers but only determine the location of insect colonisation. These wound sites do not, therefore, contribute to an increase in decomposition rate. Ultimately, trauma alters the decomposition pattern and not the decomposition rate (Cross *et al.* 2010; Smith 2014).

2.3.8 Body size

Studies have produced varying results when comparing the decomposition of adult bodies of different sizes or weights. A pioneering observational study by Mann *et al.* (1990) in Knoxville, Tennessee noted that obese human bodies rapidly lose body mass due to liquefaction of body fats. The same study noted no difference in the rate of decay between male and female bodies which tend to have different body masses (males tend to have a higher body mass than females). They noted that there were a number of conflicting cases, with no apparent explanation, where two heavier, obese bodies decomposed faster than two lighter bodies (all bodies were in the same environment 4-6m apart from one another). Another case, in the same study, was mentioned where a heavier female decomposed twice as fast as smaller male that lay nearby.

Another study on pig carcases in Poland, conducted by Matuszewski *et al.* (2014), established that in their sample, body size had a significant effect on differential decomposition rates. Body size also exhibited different gross patterns in the decomposition process. Large bodies exhibited an earlier onset of putrefaction and an extended bloating period when compared to smaller bodies. Active decay was slower with a delayed onset of advanced decay in large bodies compared to smaller bodies.

Simmons *et al.* (2010) found that, in the UK, only when a human body is exposed to access by insects is body size significant to decomposition rates. When no insect colonization is possible (i.e. sealed indoor, submerged or buried environments) then decomposition progresses at the same rate regardless of body size.

Future studies on the effect of body size on decomposition are required to better define and isolate what constitutes body size. It appears, from studies on pig models and human bodies (Mann *et al.* 1990; Simmons *et al.* 2010; Matuszewski *et al.* 2014), that body fat (which contributes to body size and body mass) plays a negligible role in decomposition rates. Muscle mass (another contributor to body size and mass) seems to be the true contributing factor to variations in decomposition rates. Further studies need to be performed to determine if this is indeed true.

There is a difference in decomposition between large adults and small children. Small children decompose faster than adults due to their greater surface-to-volume ratio (Voss *et al.* 2009). It has also been noted that children's bodies do not support as many insects as larger bodies, however their smaller bodies have less biomass to consume and thus their decomposition may be more rapid (Simmons *et al.* 2010).

2.4 Decomposition as an indicator of the postmortem interval

Understanding the various decomposition processes and their rates are necessary as they can be used as indicators to estimate a postmortem interval (PMI) (time since death), by an experienced professional, within forensic medico-legal investigations of death. Specific decomposition changes are assumed to occur at a relatively constant rate after death. Documenting these changes at a scene and extrapolating retrospectively from that point can allow for a PMI to be estimated. It is important to note that these PMIs are extrapolated and imprecise; hence the PMI is only an estimate (Shkrum & Ramsay 2007). Various fields of forensic science rely on understanding the process of decomposition. Each field focuses on different aspects of the decomposition process to make conclusions (such as PMI). Three fields within forensic science that can provide a PMI estimate based on decomposition changes include: forensic pathology, forensic taphonomy and forensic entomology.

2.4.1 Pathological PMI

A forensic pathologist may give a rough estimate of a PMI based on postmortem changes viewed at a death scene or in autopsy. Some of the variables and their general PMI estimates include the following: at the time of death vascular circulation and breathing stop, followed by the initiation of pallor, lividity and muscular relaxation are initiated. By two hours postmortem there are vascular alterations in the eyes, rigor mortis and algor mortis have initiated and lividity can clearly be observed. By four to five hours postmortem blood coagulates and lividity is fixed. From 24 hours postmortem, the cornea is dried and blood becomes re-liquefied. Around 48 hours postmortem, rigor is lost and intravascular haemolysis begins. At 72 hours postmortem, hair loss begins and nails loosen. At 96 hours postmortem skin slippage and bulla formation is observable. Bulla are isolated accumulations of fluid within the skin (Clark, Worrell & Pless 1996).

Later decomposition changes such as green discolouration, bloating, putrefaction and skeletonization are more variable and can take place anywhere between a few days to months. As such, forensic pathologists will need more information at this point to determine a PMI (Clark *et al.* 1996).

2.4.2 Taphonomic PMI

Forensic anthropologists have traditionally used their knowledge of a specific environmental area in correspondence with gross observations of soft tissue decay to estimate a PMI (Megyesi, Nawrocki & Haskell 2005). Studies by William Bass and his graduate students at the University of Tennessee set a benchmark for forensic anthropologists to determine a general estimate of PMI based on decomposition stages. These PMI estimates were very broad as the intervals were set at first day, first week, first month, first year and first decade intervals (Bass 1996).

The first day (corresponding to the fresh stage) exhibits fly egg masses (most likely Calliphoridae), blue-green discolouration of veins beneath the skin and body fluid purge from the nose and mouth. The first week (corresponding to the fresh to bloated stages) exhibits active maggot masses and activity, skin slippage, hair loss, abdominal bloating and mold growth. The first month (corresponding to the bloated, active and advanced decomposition stages) exhibits greater beetle activity and less maggot activity, collapse of the abdomen or loss of bloat due to the accumulated putrefactive gas loss, the skin is dry and leathery and adipocere may appear. The first year (corresponding to the dry stage) exhibits skeletonization and bone bleaching. The first decade exhibits signs of bone deterioration with exfoliation or flaking of bone surfaces, root growth into the bones and extensive rodent gnawing (Bass 1996).

Forensic anthropological and taphonomic PMI estimations are typically used in cases that are suspected to have a PMI of months to years and in cases where samples of insects, plants or soil are not collected or not present (Megyesi *et al.* 2005).

2.4.3 Entomological PMI

The pathological and anthropological/taphonomic methods of PMI estimation previously mentioned are qualitative in nature and their PMI estimates are quite general and unspecific. Other forensic disciplines including forensic biochemistry, botany and entomology have developed quantitative methods to estimate PMI. These provide more specific PMI estimates with narrower time ranges, especially within the discipline of forensic entomology (Megyesi *et al.* 2005).

Forensic entomology is the use of insects and other arthropods in medico-legal investigations with the primary goal of determining an estimated PMI based on uniform insect activity and life cycles (Amendt *et al.* 2007). Ammonia rich compounds and hydrogen sulfide produced by decaying bodies are stimulants for fly egg deposition. As such, flies (namely Calliphoridae or blow flies) are commonly the first colonizers of dead bodies. The growth cycle of these insects (from egg to larva, pupa and then adult) follows a specific biological succession that allows for a more accurate PMI estimation (Avila & Goff 1998; Shkrum & Ramsay 2007). As bodies progress through the decomposition stages the succession of arthropods changes. Knowledge of the various arthropod species in different geographical regions is necessary for accurate application of entomological PMI estimation (Avila & Goff 1998).

2.4.4 Variables affecting PMI estimates

A number of variables can alter decomposition rates and thus need to be factored into a PMI estimation for accuracy. Research on the effects of numerous environmental and contextual variances is ongoing so as to better understand and apply the correct principles to each unique decomposition case. Numerous variables have been found to alter decomposition rates; some of the first to be studied include rainfall, clothing, burial type and depth, ambient temperature, shelter and exposure, animal scavenging, perimortem trauma and body weight (Mann *et al.* 1990).

Regional and microenvironments have also been shown to have various effects on decomposition rates and patterns. Areas that have been studied and shown to exhibit variations include dry, desert regions causing rapid bloat and prolonged mummification (Galloway *et al.* 1989), tropical environments causing rapid skeletonization (Ubelaker 1989), wet environments causing prolonged preservation (Mellen, Lowry & Micozzi 1993), and frozen areas where thawing can also alter decomposition patterns (Micozzi 1986).

2.5 Pig models used as human analogues in forensic research

In forensic research that entails decomposition, pigs are used as a common, accepted animal model in proxy of human bodies. The use of pigs as human analogues for research, and the application of results to human cases, is based off the similarities between pigs and humans. Similarities include the distribution of fat, internal anatomy, lack of fur, and diet (Martin *et al.* 2016). Pigs are used as human proxies in research where access to human bodies for decomposition studies are not available due to restrictions by law, access and ethics. Timetables and postmortem interval equations developed on animal models cannot be used on human bodies, however general trends in decomposition rates and patterns can. Many studies using pigs as human analogues have been published (Chin *et al.* 2008; Schultz 2008; Cross & Simmons 2010; Aballay *et al.* 2012; Gruenthal, Moffatt & Simmons 2012; Myburgh et al. 2013; Matuszewski *et al*. 2014; Smith 2014; Zanetti, Visciarelli & Centeno 2014; Keough *et al.* 2015; Martin *et al.* 2016).

The results of forensic decomposition studies performed on human bodies - such as that by Megyesi *et al.* (2005) - are commonly applied and recreated in pig model studies (Cross & Simmons 2010; Myburgh et al. 2013; Matuszewski *et al.* 2014; Keough *et al.* 2015).

2.6 Total body scores

The subjective and qualitative nature of gross observations of soft tissue decay has many flaws in PMI estimation. Objective, quantitative methods are more favorable in scientific fields. Thus another method has been developed to more objectively score the level of decomposition. Megyesi *et al.* (2005) performed a human decomposition rate study in the USA that developed a 'total body score'

(TBS) system whereby the body is separated into three regions: the head and neck region, the limbs region, and the torso region. The head and neck regions includes the head, neck and cervical vertebrae; the limbs region includes the limbs, hands and feet; the torso region includes the thorax, pelvis, pectoral girdle and abdomen. The decomposition processes of each body region is divided into many sequential, quantified stages with assigned point values for each decomposition stage. Since the different body regions do not experience the same decomposition changes (e.g. limbs do not purge decomposition fluids), each body region is scored independently (Megyesi *et al.* 2005).

The total body score is out of 35 and the higher the accumulated TBS the more advanced the decomposition is (very low scores indicate fresh decomposition stages and very high scores indicate skeletonization). The lowest score possible is 3 (meaning a fresh stage in all three regions) and the highest score possible is 35 (meaning dry skeletonization in all three regions). The assignment of numerical scores allows for a quantitative analysis of decomposition, statistical hypothesis testing, and the development of regional PMI equations which assist in determining an accurate PMI (Megyesi *et al.* 2005).

Contextual differences in region and environment necessitate the development of unique TBS methods. One such variation of TBS is the 'total aquatic decomposition score' (TADS) (Heaton e*t al.* 2010). TADS is a body scoring system used for the PMI estimation of bodies that have decomposed in aquatic environments (Megyesi *et al.* 2005, Heaton e*t al.* 2010, Simmons *et al.* 2010). This system was developed on human bodies that were recovered from UK waterways (Heaton e*t al.* 2010).

The typical decomposition process and its scoring models cannot be inferred upon bodies which have been thermally altered by charring and burning. The destructive nature of fire alters the body through denaturing of muscle protein, calcination of bones, charring of soft tissue, and the destruction of body elements. A unique TBS system needs to be developed for charred bodies. One such model has been developed by Gruenthal, Moffatt and Simmons (2012) (in the UK on pig carcasses) called the 'charred body scale' (CBS). This model uses scores to determine the level of decomposition of charred remains where the head, neck and limbs are blistered and the torso differentially charred. This method is only applicable to similarly burned cases therefore a TBS system needs to be developed for each of the different burn levels. No inter observer reliability tests have been performed on this method to determine its reliability.

The advantage of using the TBS system and variances of it (such as TADS and CBS) is that they can be applied to human and animal models (animals used as human analogues). The scoring can be applied to humans and animal models because the scoring is based on decomposition changes and body regions common to both models. It is common, accepted practice to use TBS on pig models in forensic taphonomic research and the results are applied to human counterparts (Cross & Simmons 2010; Myburgh et al. 2013; Matuszewski *et al.* 2014; Smith 2014; Keough *et al.* 2015; Martin *et al.* 2016). One study has applied TBS to a rabbit model in a decomposition study (Troutman, Moffat & Simmons 2014).

Another advantage of TBS is that a study on interobserver error found that there is no significant interobserver error in the scores assigned by independent observers. The same study reported that there is also no significant difference in the scores assigned by individuals of different education levels (Dabbs, Connor & Bytheway 2016).

2.7 Accumulated degree-days

Of all the variables that affect the decomposition rate, temperature has been found by many authors to be the leading influencing factor in decomposition, both directly and indirectly (Rodriguez & Bass 1983; Galloway *et al.* 1989; Mann *et al.* 1990; Shean *et al.* 1993; Komar 1998; Weitzel 2005; Sharonowski, Walker & Anderson 2008; Michaud & Moreau 2011). Accumulated temperature drives the biological, enzymatic and arthropod activities that result in soft tissue decay. Thus forensic anthropologists are able to model decomposition as it is dependent on both time and temperature (Megyesi *et al.* 2005). Megyesi *et al.* (2005) found that temperature and time combined accounts for 80% of observed variation in human decomposition.

The measurement of Accumulated Degree-Days (ADD) is used to represent the accumulated heat energy units available for the decomposition of soft tissues over time. ADD is calculated by the sum of daily averages- that is by adding the average of maximum and minimum air temperatures per day (Megyesi *et al.* 2005; Myburgh et al. 2013).

The use of ADD in research on human and animal models in forensic decomposition studies is common and widely published Cross & Simmons 2010; Gruenthal, Moffatt & Simmons 2012; Myburgh et al. 2013; Matuszewski *et al*. 2014; Smith 2014; Troutman *et al.* 2014; Martin *et al.* 2016).

It is important to understand that the study of decomposition progression cannot be accurately modeled chronologically only. The progression of decomposition must be viewed over accumulated temperatures. Thus the decomposition of multiple bodies cannot be accurately compared by the chronological periods of their respective decomposition (the days, weeks or months). For accurate comparison of decomposition, the ADD period of the respective bodies' decomposition can be compared (Megyesi *et al.* 2005).

Regression equations have been developed to predict ADD by using TBS scores that allow for PMI estimations (Megyesi *et al.* 2005; Myburgh et al. 2013). These equations are invaluable tools yet geographically unique regions need to develop their own regression equations to account for regional differences in regards to ADD (Cockle & Bell 2015). A limitation to these equations are that certain contextual factors (including climate, sunlight, humidity, clothing, perimortem injuries, scavenging, etc.) cannot be quantified or accounted for by regression equations (Megyesi *et al.* 2005). A study by Dabbs (2010) indicated that temperatures used to predict ADD and PMI from regression equations are typically sourced from local weather stations in Australia and found that there are significant differences between the average daily temperature data supplied by research stations and the local site temperatures. Although ADD based regression equations are most commonly used by forensic anthropologists to estimate PMI, two equations have been developed by Vass (2011) to try include more variables (other than temperature and time alone) to determine a PMI. These formulae (one for surface decomposition and one for burial decomposition) also include measurements of temperature, moisture, as well as the partial pressure of oxygen in an attempt to develop a universal PMI formula that accounts for a greater number of contextual variables.

2.8 Effects of fire on soft tissue

One variable (and its effects on decomposition rates and patterns) that has been understudied is the effect of fire and charring. Fire and thermal damage often affects the soft tissues, muscles and fat. Thermal alterations are often limited to the surface regions with limited penetration. The combustible nature of soft tissue, muscle and fat allows them to act as a large constituent of the fuel load of a fire. Often they are all that is needed to sustain a fire, consequently leading to the surrounding fuel sources in the vicinity to be untouched/unscorched. Such cases have led to the ‘spontaneous human combustion’ myth (DeHaan, Campbell & Nurbakhsh 1999).

The gross morphological changes that a burning body goes through when burning depends on the temperature of the fire and the duration of the burning. A study (Bohnert, Rost & Pollack 1998) of the observed changes was performed on human bodies at a crematorium at 800^{o}C which rendered the following results:

After 10 minutes, the body assumes the “pugilistic posture”, the calvarium begins to separate from its surrounding soft tissues, facial soft tissues are charred and the soft tissues, phalanges and metacarpals of the hands are burned away. The pugilistic pose is caused by the protein fibers of the muscles becoming denatured and shortened (the stronger flexor muscles contract more than the extensor muscles leading to extreme flexion) causing the arms to move towards the torso into a ‘boxers pose’ (Saukko & Knight 2004).

After 20 minutes, the following skeletal elements begin to be exposed as their surrounding soft tissues are consumed: the facial bones (mostly zygomatics and mandible), the sternal ends of the ribs, radius and ulna. The coronal and sagittal sutures begin to separate and the mandible begins to fracture. The bones that are destroyed or calcined at this point include the sternum, carpels, metacarpals, tarsals, metatarsals and phalanges (Bohnert *et al.* 1998).

After 30 minutes, the thoracic and abdominal cavities are exposed and the anterior ends of ribs are calcined and bent inwards or outwards. Organs are blackened and shrunken. The distal ends of the long bones (arms and legs) are either extremely calcined or completely consumed (Bohnert *et al.* 1998).

After 40 minutes, the calvaria separates from the head and the blackened brain is exposed. Facial bones are calcined and fragmented, the lower arms are completely destroyed and the humeri are exposed and fractured (Bohnert *et al.* 1998).

After 50 minutes, all extremities are destroyed leaving only the fragmented skull and torso with the shrunken and unrecognizable organs (excluding the liver which may still be recognized) (Bohnert *et al.* 1998).

Complete incineration of the body occurs within two to three hours when maintained at 800^{o}C (Bohnert *et al.* 1998).

The temperatures reached in crematorium ovens are similar to those reached in house fires. The time period, however, is usually not the same, as house fires are often put out by fire-fighters. Therefore, bodies discovered in these contexts are often not entirely consumed. The same can be said for car fires; however, temperatures may be higher in car fires depending of the amount of fuel and the size of the fuel tank. Another variation from the crematorium procedure is that car and house fires usually go through phases with different temperatures whereas the temperatures in a crematorium fire is constant. Bodies found in a house fire typically only show extensive damage on the fire-exposed surfaces with minor damage to the protected surface (e.g. the body surface lying against the floor) (Bohnert *et al.* 1998).

2.9 The Crow-Glassman scale

There are various models that can be used to classify the level of burns on burn survivors. These models determine the severity of burns by classifying burns by ‘degrees’ depending on the layers of skin damaged or by the percentage of the total body surface area damaged (Tintinalli *et al.* 2010). A similar model has been developed to classify the level of postmortem damage to a body by burning called the Crow-Glassman Scale (CGS) (Glassman & Crow 1996). This scale is comprised of five levels that include singing of hair and epidermal blistering (CGS level 1) up to complete cremation of the body reducing it to ash (CGS level 5) (Glassman & Crow 1996) (Table 2.2).

Table 2.2: Crow-Glassman Scale (Glassman & Crow 1996)

Crow Glassman (CGS) level	**Description**
CGS level 1	This level constitutes minor damage to the body, damage that is typical of smoke death. Common characteristics include epidermal blistering and the singing of facial and head hair. Victim identification is possible since no identifying features are damaged or obscured.
CGS level 2	This level constitutes varying levels of charring across the body. Elements that may be missing or consumed include the hands, feet, genitalia and/or ears (full or partial). Disarticulated elements may be present near the body. Victim identification may be possible by a team comprising a forensic pathologist and forensic odontologist.
CGS level 3	This level constitutes further damage noted by the absence of major sections of the limbs. The head is present but identification is not possible by facial recognition. Disarticulated elements are further from the body. Victim identification may be possible by a team comprising a forensic pathologist, forensic odontologist and forensic anthropologist. The forensic anthropologist may be used to determine sex, age, racial affinity and stature from the recovered skeletal remains.
CGS level 4	This level constitutes damage to the skull as it is fragmented and disarticulated from the body. Portions of the limbs may still be articulated to the body. Small body fragments and dental elements may be strewn around the body
CGS level 5	This level constitutes cremation of the body with little to no tissue remaining. Body remains are fragmented, scattered and incomplete

The standardization and application of this scale assists in the communication between the multiple personnel involved in investigating burn/fire related deaths. This scale allows for the succinct and simplified recording of burn damage to a body by any person, regardless of expertise, and reduces long, subjective descriptions in records (Glassman & Crow 1996). The simplicity of describing the level of burn to an area of soft tissue allows for the use of CGS in animal studies, such as in the pig study by Gruenthal, Moffatt & Simmons (2012).

2.10 Decomposition of burned remains

Only three studies have been performed on the decomposition rates and patterns of burned bodies (Avila & Goff 1998; Chin et al. 2008; Gruenthal, Moffatt & Simmons 2012). Two of these studies mentioning burned body decomposition rates, are mostly entomological studies on the arthropod succession patterns on burnt bodies (Avila & Goff 1998; Chin *et al.* 2008). However, these two studies simply made passing reference to the decomposition rates of their samples using different methods to track the decomposition rate.

Avila and Goff (1998) performed an observational study in the Hawaiian Islands in two different habitats (a semi-arid region compared with a forested region) with pigs burned to a CGS level 2. Although the primary focus of the study was insect succession, decomposition rates between unburned and burned pigs in different locations were also compared. Differences in decomposition rates were determined by comparing the graphed curves formed by comparing time (days) plotted against the percentage of weight loss (kg). They determined that the burned carcass, in the forested region, had an increased rate of decomposition (in this case the percentage of biomass loss due to decay) compared to the unburned carcass. The semi-arid region however revealed no marked difference in decomposition rate between the burned and unburned carcasses. No explanation for the similar rates in the semi-arid region was provided (Avila & Goff 1998).

Chin *et al.* (2008) also performed an insect succession study, in Malaysia, on a pig partially burned with petrol. No specific description was given on how the decomposition rates were measured between the burned pig and the unburned control pig. It appears that the number of days it took each pig to reach each decomposition stage (fresh, bloat, active decay, advanced decay, dry/remains stages) was the measure they used to compare the decomposition rates. This study stated that no significant difference was noted between the rate of decomposition of the burned and unburned pigs (Chin *et al.* 2008).

One study has been published that provides a means of determining the stage of decomposition a body was at when postmortem burning occurred. This process depends on observing the level of thermal alteration of the surviving bones (Keough *et al.* 2015). Only one published article has studied (primarily) the differential decomposition patterns comparing charred to uncharred remains in the United Kingdom (Gruenthal, Moffatt & Simmons 2012).

A study conducted in the UK by Gruenthal, Moffatt and Simmons (2012) studied the decomposition of 48 pigs (*Sus scrofa*); 24 uncharred controls and 24 charred experimental samples. The pigs were burned differentially with the head, neck and limbs burned to a CGS level 1 and the torso burned to a CGS level 2. Using a unique Total Body Score system termed the Charred Body Scale for use on their experimental samples and Accumulated-Degree Days, the decomposition rates were quantified.

Gruenthal, Moffatt and Simmons (2012) found that charring initially resulted in a more advanced appearance of decomposition however the rates of decomposition between the controls and the experimental samples were the same. The charred limbs, head and neck decomposed significantly slower than the uncharred limbs and the charred torsos decomposed significantly faster than the uncharred torsos. Overall there was no difference in the rate of decomposition between the charred and uncharred remains.

2.11 Limitations of previous research

The study by Gruenthal, Moffatt and Simmons (2012) raises a number of questions from their results that need to be addressed.

1) Since their samples were differentially burned (head, neck and limbs received a CGS level 1 and the torsos received a CGS level 2) and each region decomposed at different rates, it is uncertain if a regional rate or CGS level affects the decomposition.

2) Since every pig was burned differentially how would a pig burned entirely to one CGS level decompose differently to another pig burned entirely to another CGS level?

3) The study focused on decomposition rates only so there is a need for a description of the decomposition patterns of burned remains.

4) No interobserver reliability test has been performed on the Charred Body Scale to determine its reliability, especially on bodies of different burn levels. As a result, potentially unique TBS methods for each CGS level needs to be developed.

5) The effects of seasonal variances need to be explored to establish if they still have any influence on decomposition rates in bodies that have been grossly modified by fire.

6) Finally, studies need to be performed in South Africa as each ecologically unique area needs to perform its own studies to cater for local variances (Parks 2011).

Chapter 3: Materials and Methods

3.1 Introduction

3.1.1 Design

The study design was a prospective, longitudinal, observational and descriptive study.

3.1.2 Ethics

Ethical approval for the study was granted by the Animal Ethics Screening Committee (AESC) (Clearance Certificate Number: 2013/20/01) (Appendix 1).

Ethical clearance was granted for the euthanasia of only five pigs by the Animal Ethics Screening Committee (AESC) for this study (four pigs were ultimately euthanized for the study). Additional pigs who had died of natural causes were sought after to increase the sample size, however, only two were successfully donated. The small sample size of this study was determined by these ethical factors.

3.2 Materials

3.2.1 Sample

The sample comprised of six domestic pigs (*Sus scrofa domesticus*). Four pigs (with a weight range of 35.8kg to 37.6kg) were obtained from the Central Animal Services (CAS) which is housed at the University of the Witwatersrand's Faculty of Health Sciences campus. They were euthanized by the CAS for the purposes of this study. The process of termination included sedating the pigs followed by an IV injection for the humane termination of animals. Sedation was performed with Katamine (11mg/kg) and Midazolam (0.3mg/kg) via intramuscular injection. Termination was performed via an intravenous overdose of sodium pentobarbitone (the drugs were sourced by the CAS from Kyron Laboratories (Pty) Ltd, PO Box 27329, Benrose, 2011). These pigs were sourced on 6 October 2014 and comprised the summer sample. Two methods of pig euthanasia are commonly used in forensic decomposition research: trauma to the head by a bolt gun or chemical euthanasia (Sharanowski *et al.* 2008; Kelly *et al.* 2009; Kolver 2009; Cross & Simmons 2010; Smith 2014; Martin *et al.* 2016). Open wounds are not appropriate for this decomposition study as it would introduce an additional variable which is not part of this study. Chemical euthanasia was chosen as the preferable method. Chemical euthanasia is a common method of pig euthanasia in decomposition studies (Kelly *et al.* 2009; Kolver 2009). The effect of chemical euthanasia on decomposition is unknown.

Two additional pigs (weight range of 17kg to 19kg) were donated by TOPIGS SA's Dorstfontein Branch (a pig breeding farm) (GPS Coordinates 25°58'39.05"S 28°36'50.47"E). According to the manager, Mr. Barend Vorster, the pigs died of natural causes most likely due to hemorrhagic bowel syndrome (HBS), commonly called red gut. HBS is commonly caused by *Lawsonia intracellularis* or

Clostridium perfringens and is a common cause of death experienced in large pig farms. These pigs were sourced on 04 July 2014 and comprised the winter sample. The cause of death is presumptive since no autopsy could be performed to definitively diagnose the cause of death since an autopsy would invalidate the use of the pigs in this study.

The use of pigs that have died of natural causes (such as HBS) or have died via chemical euthanasia is common in forensic taphonomic decomposition, however no studies have yet been published on the effects of these causes of death on decomposition rates.

Since this is a descriptive study on the effect of decomposition of soft tissue in general, the small size/weight of the pigs is not an issue. Forensic taphonomic research often uses small animal models to determine how variables affect general decomposition rates and patterns. A few examples of small sized animal models used in decomposition studies and published in international forensic journals include: piglets and small sized pigs (Simmons *et al.* 2010; Anderson 2011), rabbits (Adlam & Simmons 2007; Troutman *et al.* 2014), and even singe organs or portions of soft tissue (Aturaliya & Lukasewycz 1999). Although the implications of these studies' results are preliminary, these studies provide valuable information on the effects of multiple variables on the decomposition process (Troutman *et al.* 2014). The replication of these studies in human models is necessary, yet using small animal models as human analogues and applying their preliminary results to human cases is common, accepted practice in forensic taphonomic research and publishing.

3.2.2 Site of study

The study was conducted at Frankenwald, a research site owned by the University of the Witwatersrand (Figure 3.1). The Frankenwald site is located in Kelvin, Sandton and runs along the N3 highway. Bordering the research site are the suburbs of Sandton and the Alexandra Township. The site is approximately 31km away from Johannesburg via the N1 Western Bypass. The Jukskei River runs through the site. The site also houses the North Eastern Radio Fliers airfield. The Frankenwald site is approximately 283 hectares in total and 1519m above sea level.

This site was chosen for its relative vicinity to the University of the Witwatersrand (it is located within the greater Johannesburg region). It is a good representation of the veldt regions where burned bodies are often located and brought to the Forensic Pathology Services throughout Gauteng and South Africa.

Approval for use of this site was granted by Professor Beatrys Lacquet (Deputy Vice Chancellor: Knowledge and Information Management, Infrastructure and Operations, University of the Witwatersrand) and the Wits Legal Office after a review of the intended research, ethics approval, and an environmental impact study were performed.

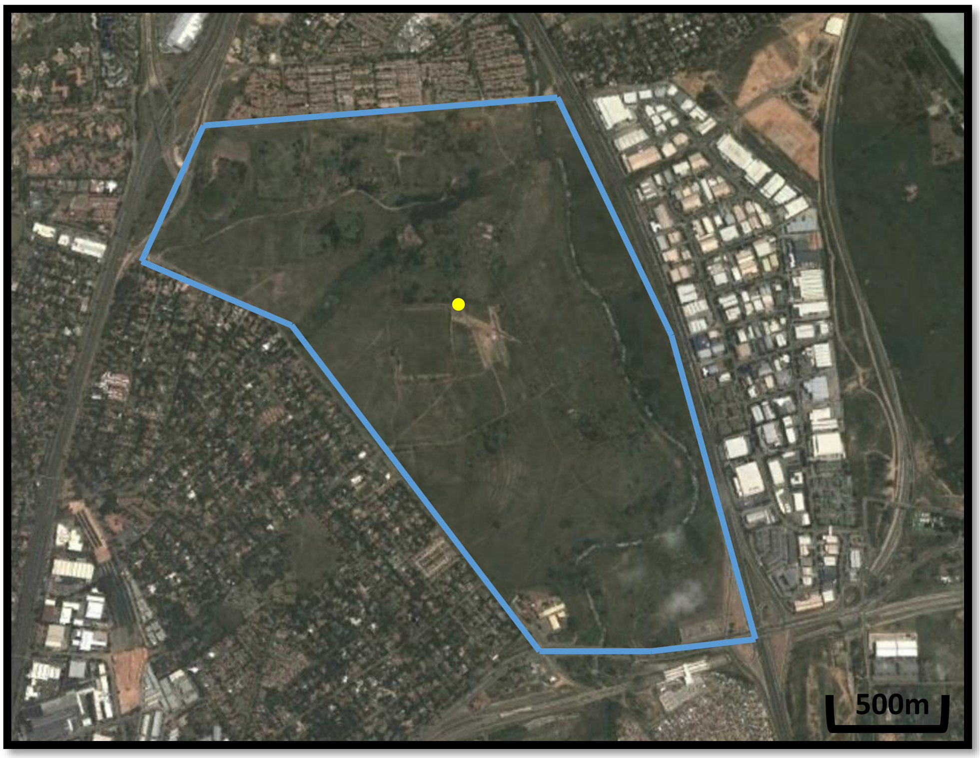

Figure 3.1: Frankenwald research site (outlined in blue; enclosure marked by yellow dot)

The enclosure for this study was approved and built by Wits' Property and Infrastructure Management Division (PIMD). The enclosure for this study is fenced off by galvanized palisade fencing measuring 10m x 10m x 2m (Figure 3.2). A locked gate on the southern side of the enclosure enables entry. Enclosed within the fence are eight galvanized cages measuring 1m x 1m x 0.5m, into which the pigs were placed (six cages were used for this study and two were used for another, separate study). The enclosure is located in direct sunlight with no shade from external structures or vegetation. The floor of the enclosure is comprised of soil with no terrestrial vegetation. The cages were placed along the sides of the enclosure, furthest from the entrance gate (in an L-shape), for easy access for observation and easy relocation of the pigs from the place of burning (at the entrance of the enclosure) to the cages. The placement of the cages also ensures that there was no difference in exposure to vegetation and sunlight. The enclosure fencing and cages protected the pigs and colonizing arthropods from large scavengers, predators and theft. The enclosure is 126 metres north-west of the North Eastern Radio Fliers airfield and is hidden from view by a large bushes (GPS coordinates 26^{o}04'14.88"S 28^{o}06'12.35"E) (Figure 3.3). The enclosure is 502 metres west of the Jukskei River and 713m east of the closest residential area.

Figure 3.2: Research enclosure and cages

Figure 3.3: Location of the enclosure in relation to the North Eastern Radio Fliers Airfield (enclosure noted by a blue square)

The Frankenwald area typically experiences mild, dry winters. In the July and August months, subzero temperatures can be reached, particularly in unprotected areas at night. The summer months are typically warm and precipitous. The summer months of November to January are most prone to experience occasional overcast and wet weather. In general, the area experiences a moderate savannah climate.

The site is a wide landscape marked by large exposure to sunshine and dominated by grass and scrub. Veldt fires (bushfires) are common at this site. Some animals sighted in the area include dogs, crows, owls, herons, guinea fowl and many termite mounds.

3.2.3 Equipment

The equipment used to burn the pigs included a barrel braai (a metal barrel/drum used for the purpose of barbequing) filled with three 15kg bags of Spar Charcoal Briquettes and six blocks of Blitz Firelighters.

Two iButtons (Maxim iButton DS1922L) were placed in two cages at the research site for the purpose of recording onsite temperatures. One iButton was used to collect the winter temperatures and the other iButton was used to collect the summer temperatures. The iButtons were placed into two condoms each (Department of Health issued Choice $_{TM}$ brand) for protection from water damage. The condoms were tied to the centre of the cage lids. The iButtons were calibrated to collect real-time temperatures hourly.

Studies have found iButtons to be reliable and accurate temperature data recording systems (Hubbart *et al.* 2005; Roznik & Alford 2012). A common issue with iButtons is that they are used in exposed environments that may experience precipitation and yet they are not waterproof (Roznik & Alford 2012). Various methods have been used by researchers to waterproof iButtons such as sealing iButtons in surgical wax, plastic tool dip, parafilm, silicone sealant, and latex materials such as balloons, condoms, or gloves (Roznik & Alford 2012). Roznik and Alford (2012) have found that waterproofing iButtons are a reliable method since they have a minimal effect on the temperature readings and reduce device failure in field conditions. This study chose to use condoms as the method of waterproofing due to its cost effectiveness. The Cold Chain Thermodynamics software program was used to retrieve the iButton data and no calibration of the iButtons was necessary.

A paired two-tailed t-test was used to compare if there was a significant difference between the temperatures measured by iButton One and iButton Two. This test was done to determine if there was a difference in the temperature measurements of the iButtons since they were placed in different locations (although close in proximity) and for accurate comparison of winter (iButton One) and summer (iButton Two) temperature measurements. Temperatures measured from 06 October 2014 to 06 November 2014 were used for the comparison as temperatures were concurrently calculated by both iButtons during this period. There was no significant difference between the temperatures provided by the two iButtons ($p = 0.8162$). The temperatures provided by iButton 1 (winter) and iButton 2 (summer) can therefore be equated.

3.3 Methods

3.3.1 Burning of pigs

The control pigs were unburned and positioned into their cages, on their right lateral side with the left lateral side facing up and exposed. No alterations were performed.

For the burning of the pigs, the coals and firelighters were lit and fanned until the coals were white and the flames burned unhindered (temperature was not recorded). The burning of the coals were kept constant. Each pig was placed directly onto the coals. The pigs were first placed onto their left side, then turned onto their right side and finally onto their abdomen. The positions were turned once the side exposed to the coals exhibited the characteristics of the desired CGS level as described by Glassman and Crow (1996) (Table 3.1). Each pig was removed from the coals just as the criteria for the desired CGS level were met. The pigs were burned in the order of their CGS level – the CGS level 1 pig was burned first, followed by the CGS level 2 pig, and lastly the CGS level 3 pig. Burning did not replicate how forensic burn cases typically burn, since this study aims to observe the decomposition of specific burn levels in relation to each other (therefore the entire body was burned to one CGS level and not to variable CGS levels).

Table 3.1: Characteristics of each CGS level Adapted from Glassman and Crow (1996)

CGS Level	Description
CGS Level 1	- Presence of burn injuries consistent with smoke death - Blistering of the epidermis - Singeing of head and body hair
CGS Level 2	- Exhibits varying degrees of charring - Destruction of body is limited to absence of hands, feet, genitalia and/or ears
CGS Level 3	- Destruction of body with portions - Head is present but identity is unrecognisable - Disarticulation of remains
CGS Level 4	- Skull is fragmented and disarticulated from the body - Portions of the arms and legs may still be articulated to the body
CGS Level 5	- Cremation of body with little or no tissue remaining - Remains are fragmentary, scattered and incomplete

The burning of the summer CGS level 1 pig took a total of 10 minutes (about three minutes per position). The burning of the winter CGS level 2 pig took a total of 20 minutes (about six minutes per position). The burning of the summer CGS level 2 pig took a total of 23 minutes (about seven minutes per position). The burning of the summer CGS level 3 pig took a total of 60 minutes (about 20 minutes per position).

The CGS level 3 pig was removed from the coals as the ears were burned off and the limbs were partially amputated. Complete amputation and consumption of the limbs by fire was avoided as this would cause problems for the scoring of the body using TBS since the limbs need to be scored as a separate body region. The partial amputation of the limbs and greater degree of charring of this pig represented a greater level of burning than the CGS level 2 pig and was thus designated/named the CGS level 3 pig.

Immediately after the pigs were burned they were positioned in their cages on their right lateral side with the left lateral side facing up and exposed.

3.3.2 Determination of seasons

According to the South African Weather Service (2016), determination of seasons in South Africa is difficult. Due to the unique and varying climatology of South Africa and regions within South Africa there is no official seasonal calendar and conventional dates are not accurate. There is disagreement at both scientific and lay levels regarding the specific dates of seasons in South Africa (South African Weather Service 2016). The South African governmental website, SouthAfrica.info (2015), provides a general period delineating seasons within South Africa. Summer generally falls within mid-October to mid-February. Winter generally falls within the months of May to July.

Since the pigs representing the effects of burns on decomposition at cooler temperatures commenced in the winter period (04 July 2014) and decomposed through a period of cooler average temperatures, they were termed the 'winter control pig' and 'winter CGS level 2 pig'. Similarly, the pigs representing the effects of burns on decomposition at warmer temperatures commenced in the summer period (06 October 2014) and decomposed through a period of warmer average temperatures, they were termed the 'summer control pig', 'summer CGS level 1 pig', 'summer CGS level 2 pig', and 'summer CGS level 3 pig' respectively.

The summer observation period was for a forecasted 1000 ADD (which amounted from 06 October to 26 November 2014). The length of the observation period was determined by when the summer control pig reached the dry stage or skeletonization (which concludes the full decomposition process). The winter group was also observed over a forecasted 1000 ADD (04 July 2014 – 13 September 2014) for comparisons between the two seasonal groups in objective four.

An unpaired two-tailed t-test was used to compare if there was a significant difference between the temperatures measured in the winter period and summer period, as recorded by the iButtons on site. This test was used to determine if the winter and summer temperatures were significantly different enough to account for any temperature-related decomposition rate differences and significant enough to term the two observation periods as 'winter' and 'summer'. The program GraphPad Instat 3 was used to run the statistical tests.

There was a significant difference between the winter and summer temperatures provided by the iButtons ($p < 0.0001$). The winter pigs experienced temperatures with a mean of 18.5^{o}C and a range of -5.9^{o}C to 44^{o}C. The summer pigs experienced temperatures with a mean of 23.1^{o} and a range of 5.9^{o}C to 43.2^{o}C. Therefore, the significant difference between the two periods - termed winter and summer - are accurate reflections of the contrasting temperatures experienced by the two pig groups.

3.3.3 ADD

Data collection occurred in 50 accumulated-degree days (ADD) intervals. The ADD intervals, used to determine when to visit the research site to record observations, were determined by calculating the *estimated* average temperature for each day by using the forecasted daily maximum and minimum temperatures supplied by the South African Weather Service for the general Sandton region. The sum of total daily averages was added each day. Data was collected on the days that reached or passed a factor of 50 ADD (Appendix 5 and 6).

The *site* ADD (the exact ADD for the site used for data analysis) for each day was downloaded from the two on-site iButtons (Maxim iButton DS1922L) by the program Cold Chain Thermodynamics. The maximum and minimum temperatures for each day of the data collection period were averaged and added. The iButtons round off hourly temperatures to three decimal places.

Base temperature is the temperature at which a biological process being studied ceases. A base temperature of 0^{o}C is commonly used in decomposition studies since at this temperature bacterial activity is inhibited and putrefaction ceases (Megyesi *et al.* 2005). Therefore, temperatures below 0^{o}C and the possible resultant freezing causes decomposition to stop and does not contribute to ADD. Hence, all minimum temperatures that were below 0^{o}C were recorded as 0^{o}C rather than negative values when calculating ADD.

Statistical tests were performed on the daily average temperatures provided by the South African Weather Service's Sandton station and the two iButtons to ensure that the data provided by the iButtons were accurate. The program GraphPad Instat 3 was used to run the statistical tests.

At the end of the observation period an unpaired two-tailed t-test was used to compare if there was a significant difference between the temperatures measured by the South African Weather Service and the iButtons to determine the accuracy of the 50 ADD intervals calculated using the South African Weather Service weather station data (Appendix 4). The daily average temperatures calculated by the South African Weather Service were compared to those calculated by iButton One from 04 July 2014 to 13 September 2014 (winter observation period) and those calculated by iButton Two from 06 October 2014 to 26 November 2014 (summer observation period). There was a significant difference between the temperatures provided by the South African Weather Service for the Sandton region and the two onsite iButtons ($p < 0.0001$). The temperatures provided by the South African Weather Service are therefore significantly lower than the onsite temperatures measured by the iButtons (refer to Appendices 4-5). As a result, the data collection did not occur at regular 50 ADD intervals as planned.

3.4 Analysis

The difference in weight and manner of death between the summer and winter pig samples limited the direct comparison between the two seasonal samples. This did not affect any of the objectives. Only two objectives compared the two seasonal pig samples – objectives two and four (a comparison between the decomposition rates of the summer and winter CGS level 2 pigs). For these objectives no direct comparisons in decomposition patterns and rates between the summer and winter CGS level pigs were made. In objective four the comparison was made by noting how each of the seasonal CGS level 2 pigs decomposed differently to their respective control pigs. Therefore, the potential effects of weight and manner of death on decomposition rate were nullified. Objectives one and three did not include the winter pig sample. Objectives five did use the winter pig sample however no direct comparisons between the winter and summer pigs were made.

3.4.1 Objective one

Objective one determined the reliability of charred body scales on analyzing the decomposition of burned remains.

Individual burned level scoring systems, unique to each burned pig (CGS level 1, CGS level 2, CGS level 3) (Tables 4.1-4.3), were developed for comparison against the CBS (Table 3.2) method. These individual burn level scoring systems were created by recording the decomposition changes observed in each body region (head and neck, torso, limbs), at each forecast 50 ADD interval, over a forecasted period of 1000 ADD. The descriptions were recorded using Data Collection Sheet 1 – Observations (refer to Appendix 2). Photographs, using a Canon SX280 HS camera, were taken of the exposed left lateral side of each pig on each 50 ADD interval. Photographs of the following body regions were taken: the full pig (head to tail), the head and neck, the fore limbs, the hind limbs, the left lateral torso, the abdomen, the back, and any other remarkable feature (i.e. insect colonization, skeletal element exposure, etc.). The decomposition descriptions in Appendices 13-18 were tabulated by grouping the descriptions into decomposition stages and were assigned scores according to the methods set out by Megyesi *et al.* (2005) (Table 3.2), and Gruenthal, Moffatt and Simmons (2012) (Table 3.2). This was done after data collection, for the summer CGS level 1, CGS level 2 and CGS level 3 pigs.

To test the reliability of the two methods, an intraclass correlation (ICC) was performed on both to determine the interobserver error of each method. To directly compare the two methods, Bland-Altman plots were developed.

Table 3.2: Charred body scale categories and scores (total score = 32) (adapted from Gruenthal, Moffatt & Simmons 2012)

Head and Neck

Stage	Points	Criteria
Fresh	1	Freshly burned appearance: taut skin, dry char, blister circles present (may have differential colour within the circle)
Early	2	Neck bloat with taut skin facially, which appears moist, and prominent blister circles; skin appears mottled (uneven) and purging of fluids from the nose may occur
	3	Neck bloat and blister circles retained with the addition of drying of the facial region and a mottled coloration
	4	Neck bloat and blister circles retained with the addition of char sloughing (ears) and cracking of skin
	5	Neck bloat and blister circles retained with a more even coloration and dry ears; green discoloration to mouth may be present.
	6	Neck bloat and blister circles persist with a desiccated face and leathery texture to neck (neck skin may be loose or perforated in appearance)
Advanced	7	Neck bloat gone and facial skin assumes a ''mask'' appearance (hallmark), loose desiccated/perforated neck tissue may remain, wet decomposition may persist in neck region
	8	Skeletonization of ≤50% of skull and neck, wet decomposition may persist in neck region, ''mask'' may slip forward; thin black desiccated tissue may be apparent
	9	Skeletonization of >50% of skull and neck, end of wet decomposition in neck region, ''mask'' may still be present as well as desiccated neck tissue
Skeletonized	10	Skeletonization of >50% of skull and neck, bones appear greasy or moist
	11	Dry bones

Torso

Stage	Points	Criteria
Fresh	1	Freshly burned appearance: taut, blister circles are prominent; char appears dry and uneven in texture
Early	2	Bloat with prominent blister circles and possible char aggregation
	3	Previous characteristics retained with the addition of skin splitting and grey tissue colour beneath char and marbling/green stomach discoloration
	4	Previous characteristics retained with the addition of bubbling beneath char, deep splits in charred tissue and char/skin sloughing
	5	Skin appears leathery and bloat is lost
Advanced	6	Intestinal herniation through areas of heaviest char (hallmark), black discoloration, and desiccation of stomach skin may occur. Bloat may be retained
	7	Previous characteristics retained with the addition of desiccation of herniated organs, opening/ collapse of the chest (≤50% rib exposure) and increased maggot mass activity
	8	Torso collapse/opening (hallmark) with increased desiccation of skin and >50% of ribs visible
Skeletonized	9	Open torso with maggot mass activity causing displacement of ribs, pectoral/pelvic girdle and vertebrae ≤50% skeletonized
	10	≤50% of torso through wet decomposition, maggot masses still active throughout torso, ≤50% pectoral/pelvic girdle and vertebrae skeletonized
	11	>50% of torso through wet decomposition, maggot masses only active in localized regions (if at all), >50% pectoral/pelvic girdle and vertebrae skeletonized
	12	Dry bones

Limbs

Stage	Points	Criteria
Fresh	1	Freshly burned appearance: char appears uneven and dry, limbs are taut with pugilistic posture, blister circles prominent and uneven coloration of skin
Early	2	Taut with pugilistic posture retained, singeing evident on edges of blister circles (prominent) and hair, char appears even in texture while skin coloration appears mottled/uneven. Peeling of epidermis may occur
	3	Taut with potential char aggregation, splits may occur in tissue, pugilistic posture retained. Peeling of epidermis with wrinkling or sloughing may occur and blister circles may persist
	4	Limbs appear withered (hallmark) with pugilistic posture retained, coloration appears even across >50% of surface, leathery in texture. Blister circles may be evident, but not prominent
Advanced	5	Desiccation of limbs (especially the feet), skin of upper portion of the leg is leathery but without looseness of skin. Pugilistic posture is retained
	6	Desiccation of limbs (especially the feet), skin of upper portion of the leg may be loose, leathery and perforated; limbs may be detached from torso. Pugilistic posture retained
Skeletonized	7	≤50% skeletonized, limbs may be detached from torso and desiccated tissue may be adherent. Pugilistic posture retained
	8	>50% skeletonized, may have desiccated tissue adherent
	9	Dry bones

3.4.1a Interobserver study of CBS and unique burn level scoring systems

An interobserver study was performed on the CBS method (Table 3.2) and on each of the unique burn level scoring methods developed by this study (CGS 1 TBS, CGS 2 TBS, CGS 3 TBS) (Tables 4.1-4.3) to determine which scoring method is more reliable for further use in this study.

A group of 9 forensic science students (at Honours and Masters level) at the University of the Witwatersrand, with knowledge of the decomposition process and patterns, were assigned the same pack of 51 photo files for the CBS interobserver test. Each photo file contained photos of a single pig at a random burn level and random decomposition stage. Each photo file included a full picture of the pig and close ups of the head and neck, belly, left lateral side, back, and limbs. They were provided with the CBS scoring method by Gruenthal, Moffatt and Simmons (2012) (Table 3.2).

Scores were assigned to the head region, torso region, limbs region, and a total body CBS score was calculated (sum of the three body region scores). The photos discussed in section 3.4.1 were used. An intraclass correlation (ICC) was used to test the absolute agreement between each of the body region CBS scores (head, torso, limbs) and the total CBS scores (Appendix 20). The statistical program Stata 13.1 was used to run a two-way random effects model (95% confidence interval) to determine absolute and individual average agreement of the head, torso, limbs, and total body scores to determine consistency of agreement of the head, torso, limbs, and total body scores. Results were rounded up to two decimal points.

Eight students were assigned the same pack of 17 photo files, each containing a photo of a pig burned to the CGS level 1 at a random stages of decomposition. Each photo file included a full picture of the pig and close ups of the head and neck, belly, left lateral side, back, and limbs. They were provided with the CGS 1 TBS scoring method developed by this study. They independently scored each pig using this method. Photos discussed in section 3.4.1 were used. Scores were assigned to the head region, torso region, limbs region, and a total body CGS 1 TBS score was calculated (sum of the three body region scores). The photos discussed in section 3.4.1 were used. An intraclass correlation (ICC) was used to test the absolute agreement between each of the body region CGS 1 TBS scores (head, torso, limbs) and the total CGS 1 TBS scores (Appendices 21). The statistical program Stata 13.1 was used to run a two-way random effects model (95% confidence interval) to determine absolute and individual average agreement of the head, torso, limbs, and total body scores to determine consistency of agreement of the head, torso, limbs, and total body scores. Results were rounded up to two decimal points.

This entire process was repeated by each of the 12 forensic students with a photo pack of 17 photo files with a pig burned to the CGS level 2 (using the CGS level 2 TBS method) and a photo pack of 17 photo files with a pig burned to the CGS level 3 (using the CGS level 3 TBS method) (Appendices 22-23).

3.4.1b Bland-Altman plots comparing the two methods

At the end of the observation period the recorded observations (recorded on Data Collection Sheet 1, refer to Appendix 2) and using the photographs, each pig was given a CBS score (out of 32) (Table 3.2) and an individual burned level TBS score - the CGS level 1 pig was given a *CGS level 1 TBS* score (out of 32), the CGS level 2 pigs were given an *CGS 2 level TBS* score (out of 29) and the CGS level 2 pig was given a *CGS level 3 TBS* score (out of 25) (refer to Tables 4.1 - 4.3 in Results section 4.2) - at each 50 ADD interval.

Since each of these assigned scores (CBS, and CGS levels 1-3) have a different total score they were all standardised as a Standardised Total Body Score (STBS) - a score out of 30. The STBS allowed for comparisons between the different scoring systems and the different pigs. STBS was calculated by using the standardized body score equation (D^{30}=30y/d) and its principles from Simmons *et al.* (2010). D^{30} means the total standardized score is 30; y = the assigned TBS, CBS, and CGS level 1/CGS level 2/CGS level 3 score; d = the maximum TBS, CBS, and CGS level 1/CGS level 2/CGS level 3 score. Standardized Body Scores were rounded off to two decimal points and were used for all comparisons and analyses (refer to Appendices 7-12).

Calculated scores were tabulated for the winter control pig (Appendix 7), winter CGS level 2 pig (Appendix 8), summer control pig (Appendix 9), summer CGS level 1 pig (Appendix 10), summer CGS level 2 pig (Appendix 11) and summer CGS level 3 pig (Appendix 12). These can be found in the Appendices.

Bland-Altman plots (using the program Analyse-it), with 95% limits of agreement, were used to statistically determine if there is a difference between the scores assigned by the CBS and the individual burn level scoring method (CGS 1 TBS for the summer CGS level 1 pig, CGS 2 TBS for the summer, and CGS 3 TBS for the summer CGS level 3 pig) in each burned pig. This would test the differences in assigned scores between the two scoring methods for each burn level. Bland-Altman plots are a statistical means to test the agreement between two scoring methods, by determining the average bias between the two methods. No p-value is provided, rather a clinical decision needs to be made, using the average bias and resultant 95% limits of agreement, if the differences in the measures between the two methods is clinically acceptable.

3.4.2 Objective two

Objective two described the decomposition patterns of unburned and burned bodies (winter control and CGS level 2; summer control and CGS level 1, CGS level 2, and CGS level 3).

The decomposition observations recorded on Data Collection Sheet 1 – Observations (Appendix 2), mentioned in 3.4.3, was used to outline a description of the decomposition patterns of each pig (summer and winter, burned and unburned pigs), at forecasted 50 ADD intervals, over a forecasted period of 1000 ADD. The decomposition patterns of the pigs were not compared but rather a description of each individual pig was presented. Other observations that were recorded included observations of arthropod colonization, weather conditions, stage of decomposition and any other notable observations (refer to Appendices 13-18). Any unique decomposition anomalies and noteworthy observations were also described and photographed. Photos of the pigs at each forecasted 50 ADD intervals over the full forecasted 1000 ADD was compiled for visual comparison.

3.4.3 Objective three

Objective three compared the rate of decomposition between the summer unburned control pig and each of the summer burned pigs (CGS levels 1-3).

Multi-level mixed effect modeling was used to determine if there was a significant difference between the decomposition rates of the different burn levels. The ADD, CGS level, and standardized body scores of the individual burn level scoring methods were modeled. The interaction between ADD and CGS level against the standardized scores were also tested. These models were tested for the summer pigs and winter pigs separately. A p-value of 0.05 was used to determine significance. The statistical program SAS Enterprise Guide 6.1 was used to perform the statistical analysis.

The assigned standardized scores for each observation interval was graphed against the actual ADD of the day the observations were made.

Photos of the summer pigs at the forecasted 1000 ADD point (for the summer pigs) and the respective standardized scores of the pigs were compared.

3.4.4 Objective four

Objective four compared the effect of seasonal temperature differences (summer and winter) on the rate of decomposition between unburned and burned bodies at a CGS level 2. The decomposition rate between the winter control pig and winter CGS level 2 pig was compared to the decomposition rate between the summer control pig and the summer CGS level 2 pig.

No direct comparison of the decomposition rates of the summer CGS level 2 pig could be made to that of the winter CGS level 2 pig due to the difference in the weights and manner of death of the two pigs. However, comparing the decomposition rates between the unburned control pig and CGS level

2 pig in summer to that in winter, does allow for inference of the effect of seasonal difference on the decomposition rate of burned remains.

Multi-level mixed effects modeling was used to determine if the there was a significant difference between the decomposition rate of the summer control pig and the summer CGS level 2 pig. This was repeated for the winter control pig and winter CGS level 2 pig. A p-value of 0.01 was used to determine significance. The results of each season were compared together. The statistical program SAS Enterprise Guide 6.1 was used to perform the statistical analysis.

The assigned standardized scores for each pig (winter and summer control and CGS level 2 pigs) at observation interval was graphed against the actual ADD of the day the observations were made.

Photos of the pigs (winter and summer control and CGS level 2 pigs) at the final forecasted 1000 ADD point and the respective standardized scores of the pigs were compared.

3.4.5 Objective five

Body region scores of the winter and summer pigs were standardized for objective five to be completed. Standardized Body Region Scores (SBRS) (with a total score of 10) were calculated by converting each body region score assigned for each pig at each 50 ADD interval for a forecasted total of 1000 ADD. The TBS scores for each of the body regions were converted to SBRS (out of a score of 10). Conversions were achieved using the following equation: $D^{10}=10y/d$ (where the Standardized Body Region Score is D^{10}; y = the assigned TBS body region score or individual burned level body region score; d = the maximum TBS or maximum individual burned level score). Standardized Body Region Scores were rounded off to two decimal points (refer to Appendix 19).

Objective five was accomplished by 1) determining if there is a significant interaction between the body region and burn level on the decomposition rate, 2) determining if each of the body regions (head, torso, limbs) decomposes at significantly different decomposition rates to each other, and 3) determining if different burn levels cause a significantly different decomposition rate in each of the body regions (head, torso, limbs).

1) Determining if there is a significant effect by the interaction between the body region and burn level on the decomposition rate was achieved by using multi-level mixed effect modelling (significance was determined at a p-value of 0.05). The standardized regional scores (head, torso, limbs) were crossed with their burn level. This was done for each seasonal pig group (winter control pig and winter CGS level 2 pig; summer control pig and summer CGS levels 1-3 pigs).

2) Determining if each of the body regions (head, torso, limbs) decomposed at significantly different decomposition rates to each other was achieved by using multi-level mixed effect modelling (significance was determined at a p-value of 0.01). The standardized body region scores (for the head, torso, and limbs regions) were compared between the winter pigs together and between the summer pigs together. This was repeated for each individual pig (winter control pig, winter CGS level 2 pig, summer control pig, summer CGS levels 1-3 pigs). The standardized body region scores (for the head, torso, and limbs regions) were graphed against ADD for each pig (winter control pig, winter CGS level 2 pig, summer control pig, summer CGS levels 1-3 pigs) for visual comparison. Photos of each comparison at the 1000 ADD point were compared.
3) Determining if different burn levels caused significantly different decomposition rates in each of the body regions (head, torso, limbs) was achieved by using multi-level mixed effect modelling (significance was determined at a p-value of 0.01). The standardized head region scores of the winter control pig and winter CGS level 2 pig were compared. The standardized head region scores of the summer control pig and winter CGS levels 1-3 pigs were compared. This was repeated for each of the body regions, in each of the season groups. The standardized head region scores for the winter control pig and winter CGS level 2 pig were graphed against ADD for visual comparison. This was repeated with graphs produced for each of the body regions (head, torso, limbs) with the winter pigs being compared and the summer pigs being compared. Photos of each body region at each burn level (control and CGS level 2 for winter pigs, control and CGS level 1-3 for summer pigs) was provided for visual comparison. Photos of each comparison at the 1000 ADD point were compared.

The statistical program SAS Enterprise Guide 6.1 was used for all statistical analysis in objective five.

Chapter 4: Results

4.1 Body scoring systems

Unique body scoring systems were developed for bodies individually burned to levels CGS level 1 (Table 4.1), CGS level 2 (Table 4.2) and CGS level 3 (Table 4.3). These were used to score each burned pig (Appendix 8, 10-12).

Each of the body scoring systems were developed by separating the observed decomposition changes into stages (fresh, early, bloat, active, advanced and dry stages). All noteworthy decomposition advances unique to each stage were listed and assigned a numerical score (Tables 4.1 – 4.3).

The names of the developed body scoring systems and their respective total scores are: CGS level 1 total body score (total score = 32), CGS level 2 total body score (total score = 29), and CGS level 3 total body score (total score = 25) (Tables 4.1 – 4.3).

4.1.1 Interobserver error of the charred body scale and unique burn level scoring methods

Both the CBS method and each unique burn level scoring method (CGS 1 TBS; CGS 2 TBS; CGS 3 TBS) had high average absolute measures correlation coefficients (ACC) in each of the body regions (total, head and neck, torso, limbs). The unique burn level scoring methods had higher average ACCs than the CBS method in each of the body regions (total, head and neck, torso, limbs) (Table 4.4).

Table 4.4: Average absolute measures correlation coefficients of the charred body scale method and unique burn level scoring methods

Body region score	Charred body scale (CBS)	CGS 1 TBS	CGS 2 TBS	CGS 3 TBS
Total body scores	0.97	0.99	0.99	0.97
Head and neck scores	0.97	0.99	0.98	0.96
Torso scores	0.96	0.99	0.98	0.97
Limbs scores	0.93	0.98	0.99	0.95

All of the unique burn level scoring methods (CGS 1 TBS; CGS 2 TBS; CGS 3 TBS) had higher individual ACC (fewer individual interobserver errors) in each of the body regions (total, head and

Table 4.1: CGS level 1 total body score categories and scores (total score = 32)

	Head and Neck		Torso		Limbs	
Stage	**Points**	**Criteria**	**Points**	**Criteria**	**Points**	**Criteria**
Fresh	1	Freshly singed hair, blistering of the epidermis, protected and unburned areas (such as inside mouth and behind ears) white/pink	1	Freshly singed hair, prominent blister circles, slight and uneven charring, flesh beneath epidermis white/pink	1	Freshly singed hair, prominent blister circles, slight and uneven charring, flesh beneath epidermis white/pink, no pugilistic pose
Early	2	Tissue fluid purge from mouth or nose, tongue and oral cavity turn dark red/black	2	Cracking of flesh on the back, tissue fluid purge or bleeding from flesh crack	2	Haemorrhaging within exposed muscle tissue (white flesh beneath epidermis exhibiting isolated red areas)
Bloat	3	Protruding tongue, skin splitting on neck, neck distention	3	Onset of bloating, herniation of intestines, onset of epidermal blistering	3	Onset of blistering at limb joints
	4	Massive tissue fluid purge from nose and mouth, epidermis appears moist, epidermal haemorrhaging, putrefaction of eyes and tongue	4	Bloat prominent at abdomen or back and anus, blisters enlarged and fluid-filled	4	Limbs no longer extended out straight, blisters enlarged and fluid-filled
Active	5	Bloat is lost, active wet decomposition of flesh beneath skin, skin maintained with holes	5	Deflation of abdomen, massive tissue fluid purge, blister circles maintained, blackening of skin	5	<50% exposure of bone (typically onset begins at the mid-limb (ulna and radius))
	6	Wet decomposition with minimal mandibular and/or maxillary bone exposure, skin maintained with holes	6	Wet decomposition of flesh with minimal rib exposure, rib cage still fleshed, blister circles persist		
Advanced	7	≤50% of skull skeletonized, skin is leathery and mask-like, skin holes present or missing at eyes, cheeks, throat and lips	7	Ribs exposed, skin is leathery, organs putrefied, muscles mostly wet decomposition	6	>50% of mid-limbs (radius & ulna) skeletonized, blister circles persist
	8	≤50% of skull and neck skeletonized, cervical vertebrae of neck exposed	8	≤50% skeletonized (exposure of ribs and vertebral column, sternum, scapulae and/or pelvis)	7	>50% upper limbs (femur) and mid-limbs skeletonized
	9	Skin desiccated and loose/separated from skull,				
Dry	10	>50% skeletonized with greasy bone	9	>50% skeletonized	8	>50% lower limbs (tarsals and phalanges), mid-limbs and upper limbs skeletonized
	11	Skeletonized with greasy bone	10	Skeletonized with greasy bone		
	12	Dry bone	11	Dry bone	9	Dry bone

Table 4.2: CGS level 2 total body score categories and scores (total score = 29)

<table>
<tr><th colspan="3">Head and Neck</th><th colspan="2">Torso</th><th colspan="2">Limbs</th></tr>
<tr><th>Stage</th><th>Points</th><th>Criteria</th><th>Points</th><th>Criteria</th><th>Points</th><th>Criteria</th></tr>
<tr><td>Fresh</td><td>1</td><td>Freshly burned appearance with differential char, char appears dry, cracked skin reveals white flesh beneath</td><td>1</td><td>Freshly burned appearance with differential char, char appears dry, cracked skin reveals white flesh beneath</td><td>1</td><td>Freshly burned appearance with differential char, char appears dry, cracked skin reveals white flesh beneath, pugilistic pose</td></tr>
<tr><td>Early</td><td>2</td><td>Skin on neck split, large open wounds/holes on neck and snout, tissue fluid purge, char mottled and flaky</td><td>2</td><td>Cracks in skin larger, onset of intestinal herniation, char mottled and flaky</td><td>2</td><td>Haemorrhaging within exposed muscle tissue (white flesh beneath epidermis exhibiting isolated red areas), char mottled and flaky, cracking of skin widened</td></tr>
<tr><td rowspan="2">Bloat</td><td>3</td><td>Neck bloat, neck skin split, deep tissue splits in snout and neck, tissue fluid purge and tissue seepage from tissue splits</td><td>3</td><td>Onset of bloat, skin cracks wide, intestines exposed and bloated, large and deep splits in the flesh</td><td>3</td><td>Legs extended due to bloat, pugilistic pose retained, tissue fluid purge</td></tr>
<tr><td>4</td><td>Char moist and flattened (no longer flaky)</td><td>4</td><td>Char moist and flattened (no longer flaky)</td><td>4</td><td>Char moist and flattened (no longer flaky)</td></tr>
<tr><td rowspan="2">Active</td><td rowspan="2">5</td><td rowspan="2">Bloat lost, large open wound-like holes, skin cracked open on neck, skin is moist</td><td rowspan="2">5</td><td rowspan="2">Bloat is lost and abdomen caving in, large laceration-appearing holes in flesh, flesh beneath char brownish, char and skin appears moist, blister circles persist</td><td>5</td><td>Large holes in flesh, char and skin appears moist</td></tr>
<tr><td>6</td><td><50% exposure of bone (typically onset begins at the mid-limb (ulna and radius))</td></tr>
<tr><td rowspan="2">Advanced</td><td>6</td><td>≤50% skeletonization of head and neck, skin is leathery, only black charred skin remains</td><td rowspan="2">6</td><td rowspan="2">≤50% skeletonization of torso, ribs may be disarticulated, skin is leathery, organs putrefied</td><td>7</td><td>>50% of mid-limbs (radius & ulna) skeletonized, blister circles persist</td></tr>
<tr><td>7</td><td>Skin leathery and mask-like, separating from the bone</td><td>8</td><td>>50% upper limbs (femur) and mid-limbs skeletonized</td></tr>
<tr><td rowspan="3">Dry</td><td>8</td><td>>50% skeletonized with greasy bone</td><td>7</td><td>>50% skeletonized with greasy bone</td><td rowspan="2">9</td><td rowspan="2">>50% lower limbs (tarsals and phalanges), mid-limbs and upper limbs skeletonized</td></tr>
<tr><td>9</td><td>Skeletonized with greasy bone</td><td>8</td><td>Skeletonized with greasy bone</td></tr>
<tr><td>10</td><td>Dry bone</td><td>9</td><td>Dry bone</td><td>10</td><td>Dry bone</td></tr>
</table>

Table 4.3: CGS level 3 total body score categories and scores (total score = 25)

<table>
<tr><th colspan="3">Head and Neck</th><th colspan="2">Torso</th><th colspan="2">Limbs</th></tr>
<tr><th>Stage</th><th>Points</th><th>Criteria</th><th>Points</th><th>Criteria</th><th>Points</th><th>Criteria</th></tr>
<tr><td>Fresh</td><td>1</td><td>Severe char, dry appearance, hard appearance</td><td>1</td><td>Severe char, dry appearance, hard appearance, areas where skin has char has peeled as a large flake exposing underlying muscle, large longitudinal crack in flesh present</td><td>1</td><td>Severe char, dry appearance, skin slippage where revealing white muscle beneath skin, pugilistic pose, limbs severed at joints (near amputation)</td></tr>
<tr><td>Early</td><td>2</td><td>Flaking of char, tissue fluid purge from nose and mouth</td><td>2</td><td>Flaking of char, skin separating from muscle as sheets in places, tissue fluid purge from anus</td><td>2</td><td>Cracks in flesh at flanks with tissue fluid leakage</td></tr>
<tr><td rowspan="3">Active</td><td rowspan="3">3</td><td rowspan="3">Char appears moist, slippage of char, biomass decrease, caving in of skin, holes formed in skin</td><td rowspan="3">3</td><td rowspan="3">Collapse of abdomen, pooling of tissue fluid in flesh cracks, muscle beginning to breakdown revealing muscle strands, char appears moist</td><td>3</td><td>Exposed muscle tissue darkens to brown</td></tr>
<tr><td>4</td><td>Char slippage, char slippage, muscle beginning to breakdown revealing muscle strands, char appears moist</td></tr>
<tr><td>5</td><td><50% exposure of bone (typically onset begins at the mid-limb (ulna and radius))</td></tr>
<tr><td rowspan="2">Advanced</td><td>4</td><td>Holes in skin, large cavity in throat and neck, char sloughed off</td><td>4</td><td>Char sloughed off, holes in chest and abdomen</td><td>6</td><td>>50% of mid-limbs (radius & ulna) skeletonized</td></tr>
<tr><td>5</td><td>≤50% skeletonized, bone exposure but covered in mask-like skin</td><td>5</td><td>≤50% skeletonized, biomass decrease (putrefaction of organs), char moist and mottled, skin leathery and separated from bones in sheets</td><td>7</td><td>>50% upper limbs (femur) and mid-limbs skeletonized</td></tr>
<tr><td rowspan="3">Dry</td><td>6</td><td>≥50% skeletonized</td><td>6</td><td>≥50% skeletonized</td><td rowspan="2">8</td><td rowspan="2">>50% lower limbs (tarsals and phalanges), mid-limbs and upper limbs skeletonized</td></tr>
<tr><td>7</td><td>Skeletonized with greasy bone</td><td>7</td><td>Skeletonized with greasy bone</td></tr>
<tr><td>8</td><td>Dry bone</td><td>8</td><td>Dry bone</td><td>9</td><td>Dry bone</td></tr>
</table>

neck, torso, limbs) than the CBS method. The only exception was the CGS 3 TBS head and neck region scores which had a lower individual ACC (0.74) than the CBS head and neck region scores (individual ACC = 0.76). The CGS 1 TBS method and CGS 2 TBS method had particularly higher individual ACCs, in each body region, than the CBS ACCs (Table 4.5).

Table 4.5: Individual absolute measures correlation coefficients of the charred body scale method and unique burn level scoring methods

Body region score	Charred body scale (CBS)	CGS 1 TBS	CGS 2 TBS	CGS 3 TBS
Total body scores	0.81	0.95	0.94	0.82
Head and neck scores	0.76	0.94	0.85	0.74
Torso scores	0.73	0.93	0.87	0.82
Limbs scores	0.63	0.84	0.89	0.68

4.1.2 Agreement between the charred body scale and unique CGS level TBS methods

There is poor agreement between the CBS and CGS level 1 methods, with the CBS method overestimating decomposition scores with an average bias of 2.31 points with a standard deviation of 2.24. The 95% lower limit of agreement is -6.70 and the upper limit of agreement is 2.07. The limits of agreement include zero therefore there is some agreement in scores between the CBS and CGS level 1 methods (Figure 4.1).

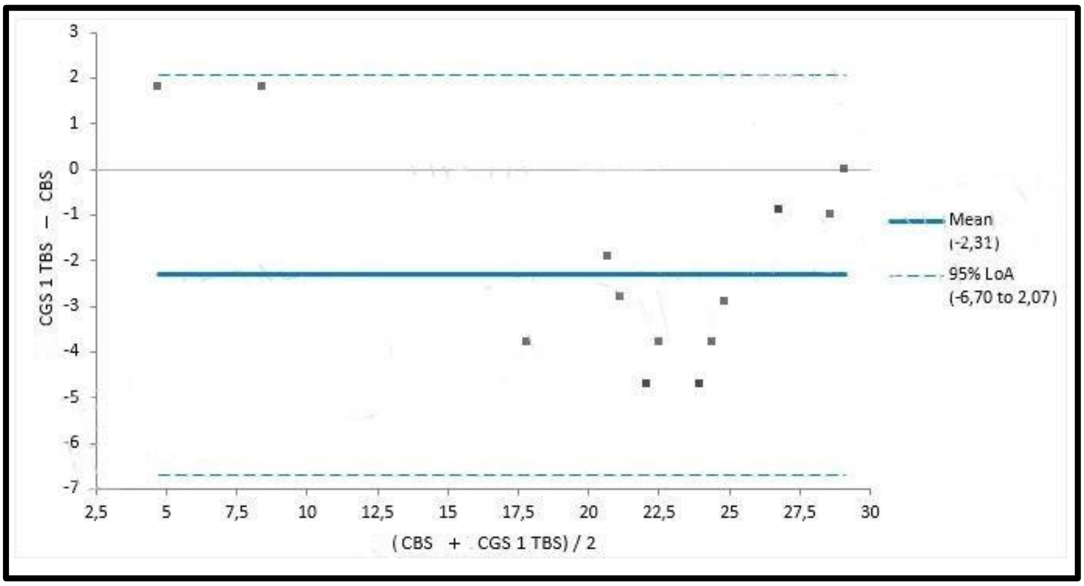

Figure 4.1: Bland-Altman plot displaying the level of agreement between the charred body score method and CGS level 1 total body score method

There is poor agreement between the CBS and CGS level 2 methods, with the CBS method overestimating decomposition scores with an average bias of 3.91 points with a standard deviation of 2.10. The 95% lower limit of agreement is -8.02 and the upper limit of agreement is 0.19. The limits of agreement include zero therefore there is some agreement in scores between the CBS and CGS level 1 methods (Figure 4.2).

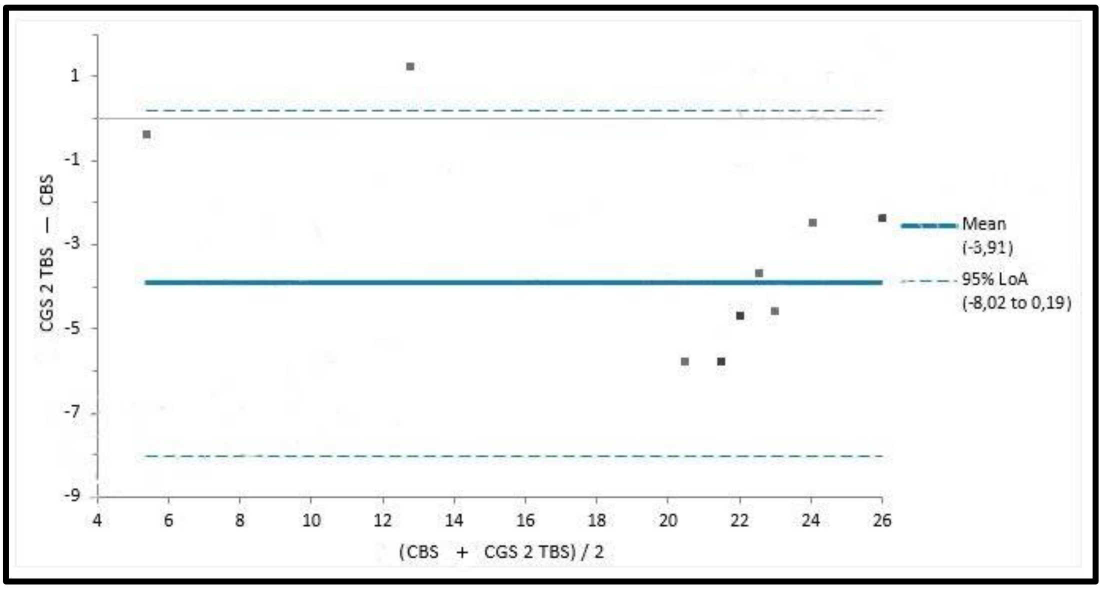

Figure 4.2: Bland-Altman plot displaying the level of agreement between the charred body score method and CGS level 2 total body score method

There is poor agreement between the CBS and CGS level 3 methods, with the CBS method overestimating decomposition scores with an average bias of 2.55 points with a standard deviation of 1.73. The 95% lower limit of agreement is -5.95 and the upper limit of agreement is 0.85. The limits of agreement include zero therefore there is some agreement in scores between the CBS and CGS level 1 methods (Figure 4.3).

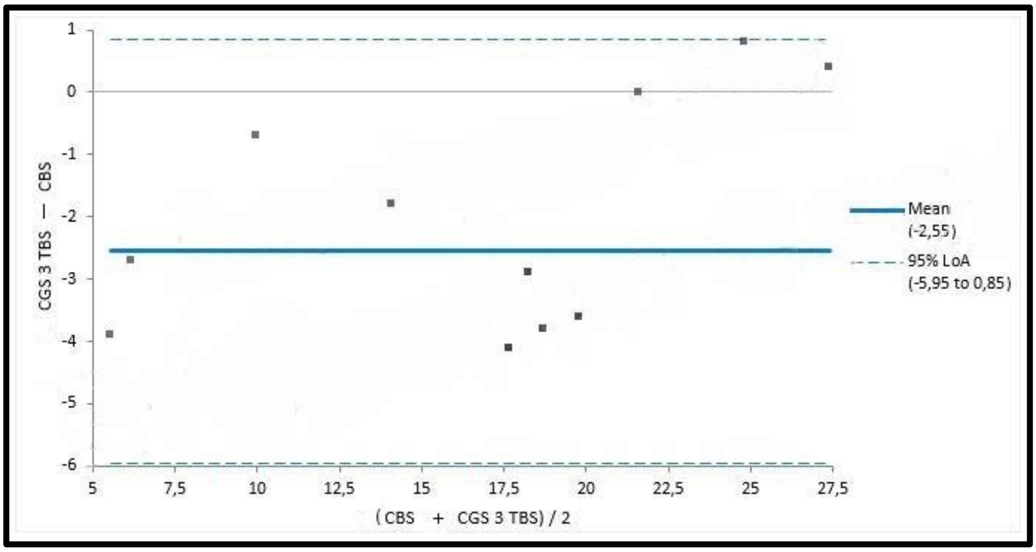

Figure 4.3: Bland-Altman plot displaying the level of agreement between the charred body score method and CGS level 2 total body score method

4.1.3 Summary

Since the interobserver error ICC and Bland-Altman plots showed the unique burn level scoring methods (CGS 1 TBS; CGS 2 TBS; CGS 3 TBS) to be more reliable than the CBS method, the unique burn level scoring methods were used for the remainder of this study.

4.2 Decomposition patterns

4.2.1 Decomposition pattern of the winter control (unburned) pig

The decomposition of the winter control pig proceeded as expected with no abnormal changes to the usual decomposition stage progression as described in previous literature (as supplied in the literature review). Observed early stage decomposition alterations included the early blue/green discolouration of the abdomen soon after death which spread to the back of the pig by 50 ADD (day six). This discolouration was also observed at the neck and face areas of the pig, occurring concurrently with body fluid purge from the nose at 200 ADD (day 19).

Expected bloat stage changes began at 250 ADD (day 25) with bloat beginning to exhibit in the torso followed by a marked increase in tissue fluid purge from the mouth and nose from 300 to 350 ADD (days 27-31). Flesh from the head began to show signs of wet decomposition at 400 ADD (day 35). The onset of marbling of the neck, torso and limbs were all observed at the same time, at 450 ADD (day 38), as well as skin slippage on the head. Bloat was first observed in the neck at 500 ADD (day 41) and skin slippage also appeared on the abdomen at this period. Increased bloat of the torso at 500 ADD had caused the pig to roll over onto its back. Marbling had reached the limbs by 550 ADD (day 45). Bloating had ceased in the neck at 550 ADD however bloating was still prevalent in the torso.

At 600 ADD (day 49), the skeletal elements began to be exposed at the head through holes in the decomposing skin. At 650 ADD (day 52) maggot activity was first observed with large maggot masses in the neck, mouth and beneath the skin of the abdomen. At 750 ADD (day 59) maggot masses were no longer present at the head/neck and torso regions and were replaced by the presence of pupae. The abdomen had deflated at 750 ADD (deflation of the neck occurred sooner at 550 ADD). Maggot activity was present at the limbs.

At 850 ADD (day 66) skin desiccation and hair loss of all body regions was observable with no maggot activity present at any body region. Skeletal elements (ribs) were beginning to be exposed through the torso at 950 ADD (day 71).

For a more comprehensive description refer to Appendix 13. For a visual representation of the decomposition process refer to Figure 4.4 (refer to page 49).

4.2.2 Decomposition pattern of the winter CGS level 2 pig

The observed decomposition of the winter CGS level 2 pig varied considerably from the unburned control pig. The initial rate of decomposition was faster than the control pig, however the active decomposition stage was longer and the advanced decomposition stage was markedly prolonged when compared to the control pig. Some typical decomposition signs (such as hypostasis, marbling and extreme bloat) were either unobservable or missing due to the thermal alteration of the tissues.

At the onset of the observation period, directly following the burning of the pig, the skin exhibited differential charring of the skin and flesh. White circular patches were present on the skin that weren't charred but rather the hair was singed. The skin also exhibited large cracks, exposing the underlying muscle. Cracking was present at the abdomen and back but was most prominent at the limb joints. The pig had assumed the pugilistic pose.

Early decomposition changes were observed at 50 ADD (day six) with skin slippage at the torso and flaking of charred skin on the limbs. The previously noted skin cracks had also become deeper and longer. At 100 ADD the charred skin had a moist, sticky appearance and the exposed muscle appeared dried. Tissue fluid purge out of the nose was first noted at 150 (day 15) ADD.

The onset of bloat in the torso was first noted at 200 ADD (day 19) (bloat in the neck occurred later at 600ADD), however it was very slight and difficult to observe when compared to the control pig's bloat onset. Charred skin began to flake on all body regions at 250 ADD (day 25). A deep, long laceration-like split/crack appeared across the back of the pig at 250 ADD.

Maggot activity was first noted at 350 ADD (day 31) in the mouth, throat and back 'laceration' split. Wet decomposition was first observed in the back laceration area at 450 ADD (day 38). The bloat stage in the torso appeared to be completed at 500 ADD (day 41) since the abdomen and back appeared to have sagged or caved in. Very slight bloat of the neck appeared at 600 ADD (day 49). Tissue fluid purge was also observed exiting the back laceration at this period.

At 700 ADD (day 56) the charred skin no longer appeared flaky but rather was moist and flattened. Minimal beetle activity was noted at 750 ADD (day 59). At 800 ADD (day 63) increased concavity of the abdomen was observed. A maggot mass was observed in the left hind limb, beneath the skin, at 850 ADD. Bloat of the neck area ceased at 900 ADD (day 69) as the neck appeared caved in.

A steady increase in deflation of the torso region, the appearance of holes in the skin of the face and an increase in cracks in the neck and limbs were observed at 950 ADD (day 71).

For a more comprehensive description refer to Appendix 14. For a visual representation of the decomposition process refer to Figure 4.4 (refer to page 49).

4.2.3 Decomposition pattern of the summer control (unburned) pig

The decomposition of the summer control pig proceeded as expected with no abnormal changes to the usual decomposition stage progression as described in previous literature (as discussed in the literature review). Decomposition was notably more rapid than the winter control pig, as was expected.

Decomposition signs representative of the bloat stage occurred rapidly and were observed in all body regions at 50 ADD (day three). Hypostasis, marbling and blistering of the skin were also present. Skin slippage and intestinal herniation occurred at 100 ADD (day five). Maggot masses were also present at 100 ADD.

Wet decomposition (indicative of the active decomposition stage) was observed at 150 ADD (day eight) with signs of skin slippage, hair loss and abdominal deflation. Skeletal elements began to be exposed in the limbs at this point. Large skin holes were present in all body regions at 250 ADD (day 13) and maggot activity ceased. Beetle activity was first detected at 400 ADD (day 21).

Desiccation of the skin began at 400 ADD and continued to dry for the rest of the observation period. Exposure of the skeletal elements increased at 450 ADD (day 23) with skeletal elements observable at the limbs as well as exposure of the mandible at 500 ADD (day 26). The pig remained in the advanced decomposition stage for a prolonged period until the end of the forecasted observation period at 1000 ADD (day 52).

For a more comprehensive description refer to Appendix 15. For a visual representation of the decomposition process refer to Figure 4.4 (refer to page 52).

4.2.4 Decomposition pattern of the summer CGS level 1 pig

The observed decomposition of the summer CGS level 1 pig varied considerably from the unburned control pig. The overall rate of decomposition was faster than the control pig and reached the latest decomposition stage (dry stage/skeletonization) more rapidly than all the pigs in this study.

At the onset of the observation period, directly following the burning of the summer pig, the CGS 1 pig exhibited blistering of the skin, including blister circles of various sizes indicating blisters that had already broken. The hair on the pig was singed and minimal patches of black charring were present on the neck, rump and limbs. The skin had split in the limb regions as well as on the left lateral side of the back. The skin still appeared pink and fresh in multiple areas, most notably around the mouth. The pig had assumed the pugilistic pose in the forelimbs.

Multiple cracks in the skin and flesh were caused by the burning process. Additional cracks in the flesh were formed and observed at 50 ADD (day three) in the neck, back and limbs. Bloating was observed at 100 ADD (day five) in the tongue (including tissue fluid purge from the mouth and nose) and the torso region. Bloating was abnormal in this pig (compared to the control) being exhibited in the form of intestinal herniation and bloating of the back (not the abdomen). This bloating of the back caused the skin to split with a hump being formed (described in greater detail in section 4.2.7).

The active decomposition stage was very short as deflation was observed at 150 ADD (day eight) (including the loss of the back hump) and skeletal elements (ribs) were already exposed (marking the initiation of the advanced decomposition stage had initiated). The soft tissues rapidly decomposed leaving behind the skin and skeletal elements.

More than half of the skeletal elements were exposed from 500 ADD (day 26). Complete skeletonization (with no skin adhesion) was first observed at 900 ADD (day 47).

For a more comprehensive description refer to Appendix 16. For a visual representation of the decomposition process refer to Figure 4.4 (refer to page 52).

4.2.5 Decomposition pattern of the summer CGS level 2 pig

The observed decomposition of the summer CGS level 2 pig varied notably from the unburned control pig. The overall rate of decomposition occurred more rapidly and reached a later decomposition stage (dry stage/skeletonization) faster than the control pig but later than the summer CGS level 1 pig.

At the onset of the observation period, directly following the burning of the summer CGS level 2 pig, the skin exhibited differential charring of the skin and flesh. Black char covered most of the skin and was superficial. White circular patches were present on the skin that weren't charred but rather the hair was singed (mostly in the hind quarters). The skin also exhibited large cracks in the charred skin exposing the underlying muscle. Cracking of the skin was present in the back and limbs but was most prominent at the abdominal region. The pig had assumed the pugilistic pose.

Multiple cracks in the skin and flesh were caused by the burning process, however, additional cracks in the flesh were noted at 50 ADD (day three) in the neck, back and limbs. Signs of bloat and notable tissue fluid purge were observed from the nose and mouth, as well as abdominal intestinal herniation and peculiarly, expulsion of the snout disk. The snout disk was observed being forcefully ejected from the nose by internal gas build up.

At 100 ADD (day five) slight bloating of the neck was observed, however bloat was lost in the torso as the abdomen appeared deflated. Maggot activity was noted at 100 ADD.

Bloat in the neck had reduced by 150 ADD (day eight) and was replaced by skeletonization of the neck and mandibular ramus. Skeletonization and active decay was observed in the torso with the ribs and vertebral column exposed. Some ribs had disarticulated from the vertebrae and were found positioned a small distance (a number of centimeters) away from the rib cage.

Skeletonization of the hind limbs was first observed at 200 ADD (day 10) with a marked decrease in the number of maggots and a sharp increase in the number of beetle activity.

Skeletal exposure was more rapid in the head and torso regions compared to the pelvic and limb regions. From 800 ADD (day 40) more than half of the pig was skeletonized.

For a more comprehensive description refer to Appendix 17. For a visual representation of the decomposition process refer to Figure 4.4 (refer to page 52).

4.2.6 Decomposition pattern of the summer CGS level 3 pig

The observed decomposition of the summer CGS level 3 pig varied from the unburned summer control pig. The overall rate of decomposition for the summer CGS level 3 pig was faster than the summer control, however the early stage of decomposition was more prolonged than noted in all the burned summer pigs, including the control pig. This pig reached a later decomposition stage (dry stage/skeletonization) sooner than the control pig and at the same time as the summer CGS level 2 pig.

At the onset of the observation period, directly following the burning of the pig, the pig exhibited heavy charring of the skin and flesh. The majority of the exposed surfaces were charred, with the exception of the medial surfaces of the limbs. The rump exhibited multiple white circular patches on the skin that weren't charred, which was indicative of the hair being singed. The charred skin presented large cracks in the skin, exposing the underlying muscle in the forelimbs and back. Unlike in the CGS level 2 pig, cracking was not present in the torso. The limbs of the summer CGS level 3 pig were severed at the joints (near amputation) due to the fire damage. The pig had assumed the pugilistic pose.

As was observed in the other burned pigs, the skin presented with new cracks in the skin, a large laceration-like split in the back flesh and tissue fluid purge from the nose at 50 ADD (day three). Tissue fluid purge was noted from the anus at 100 ADD (day five).

At 150 ADD (day eight) skin slippage and peeling/flaking of char was observed in all body regions and pooling of blood was noted in the back 'laceration'. No signs of bloat were observed at any point however at 150 ADD the abdomen appeared to have collapsed. This is a sign of post bloat or internal decomposition. Maggot activity was also first noted at this time frame.

At 200 ADD (day 10) a large hole was observed in the abdomen and skeletal exposure of a radius in one of the limbs was noted. The neck appeared caved in at 250 ADD (day 13) with the presence of a large hole in the throat and dorsal neck area respectively. The spinal column had become exposed. The skeletal elements of the pelvis were exposed at 300 ADD (day 16), as was the exposure of a single rib. From 350 ADD (day 18) more skeletal elements began to become exposed in the limbs, torso and head regions. At 400 ADD (day 21), the first signs of beetle activity were noted. By 800 ADD (day 40) more than half of the skeletal elements were exposed.

For a more comprehensive description refer to Appendix 18. For a visual representation of the decomposition process refer to Figure 4.4 (refer to page 49).

4.2.7 Unique decomposition anomalies

A number of anomalies were observed in the decomposition process of the burned pigs that needed to be highlighted. The summer CGS level 1 pig exhibited abnormal bloating at 100 ADD (day five). Instead of abdominal bloating, the bloat was exhibited dorsally by forming a large back hump (Figure 4.5). This hump caused the skin along the back to split open along the cranio-caudal axis (Figure 4.6).

The snout disk (the cartilaginous disk attached to the tip of the pig's snout by muscles) of the summer CGS level 2 pig's nose was forcefully expelled from the nose at 50 ADD (day five) (Figure 4.7).

An abnormal bloating pattern occurred in all burned pigs, with the exception of the summer CGS level 1 pig, as all the burned pigs displayed very minimal signs of bloat. Typically, very slight bloat could only be observed at the neck, however the summer CGS level 3 pig displayed no signs of bloating at all. The bloat stage was very short in the summer burned pigs. All the summer pigs (except for the CGS level 3 pig) exhibited intestinal herniation, whereas neither of the winter pigs experienced intestinal herniation. Notably the winter CGS level 2 pig did not show any major external signs of decomposition for over 350 ADD (from 650 ADD to 1000 ADD – over 21 days) and appeared preserved.

4.2.8 Other noteworthy observations

A number of noteworthy observations unrelated to the decomposition patterns of the pigs were recorded. The tissue fluid purge from the nose and mouth of each pig pooled beneath the heads of each pig and caused depressions in the soil. These soil depressions remained unaltered for the entire duration of the data collection period. In addition, the tissue fluid purge stained the soil dark and could be easily distinguishable from the surrounding, unaltered soil. The manual moving of the pigs from the metal barrel drum braai to their respective cages caused the charred skin to crack visibly and was easily distinguishable since the charring caused no other skin cracks immediately at the burning period. This could be potentially be used as a method of determining whether a body had been moved after burning in a forensic context. All burned pigs exhibited large, deep cracks in their backs (cranio-caudal axis) (potentially an area of thick cutaneous fat layers) (Figure 4.8).

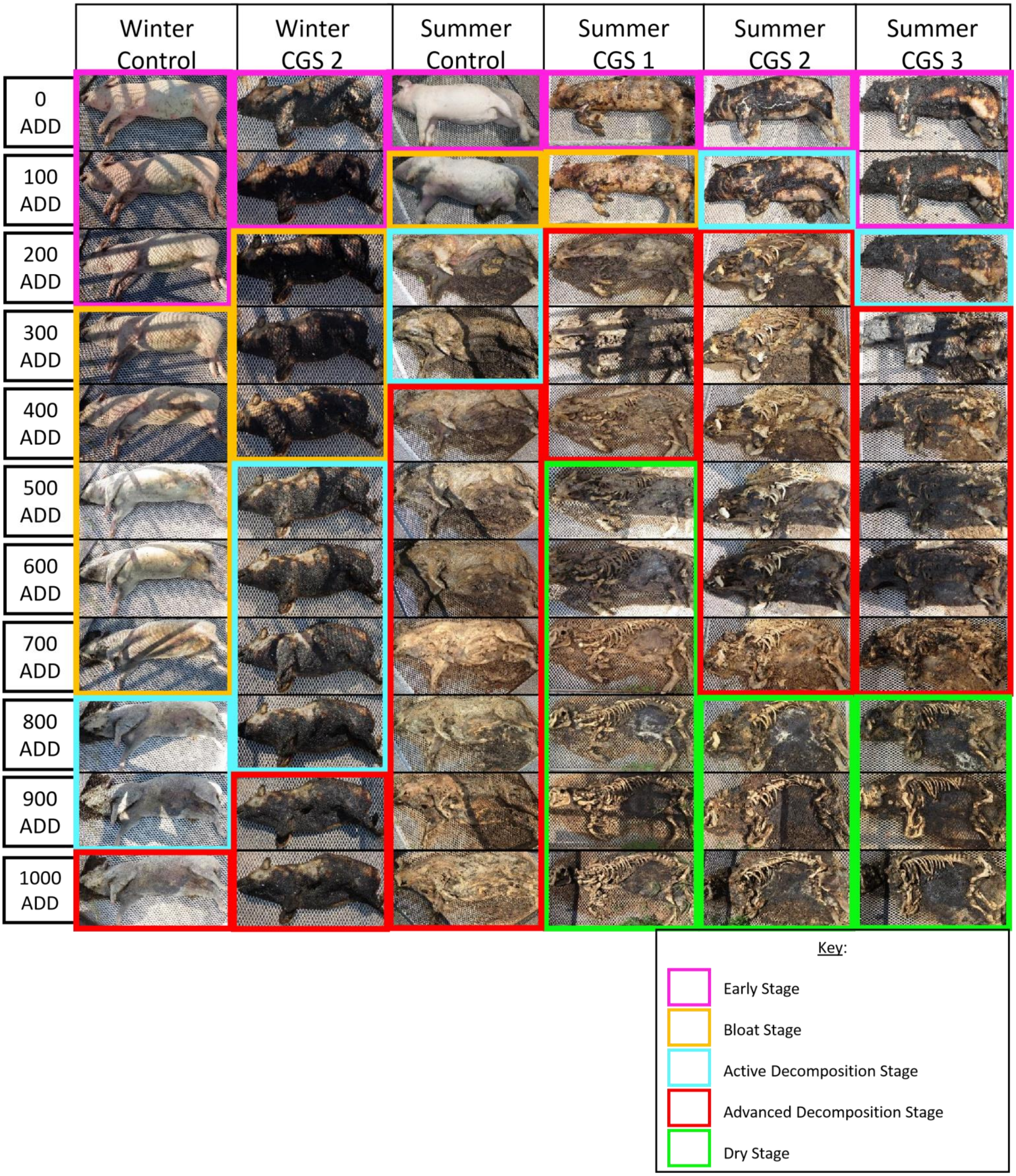

Figure 4.4: Visual representation comparing the decomposition of each pig over 1000 ADD, at 100 ADD intervals

Figure 4.5: The left lateral torso of the summer CGS level 1 Pig showing the bloated back hump (arrow)

Figure 4.6: The posterior torso of the summer CGS level 1 pig showing the bloated back hump (arrow)

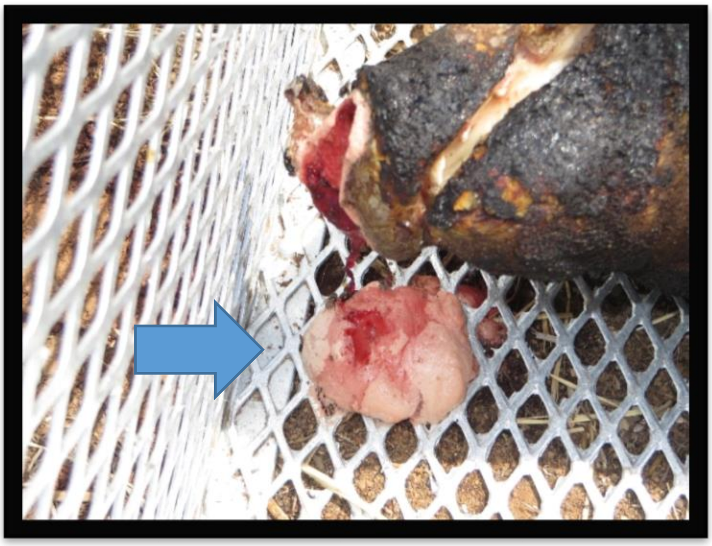

Figure 4.7: The expelled cartilaginous snout disk (arrow) of the summer CGS level 2 pig's nose

Figure 4.8: Back crack in winter CGS level 2 pig, representative of back cracks (arrow) in all burned pigs

4.3 Decomposition rates of different burn levels

4.3.1 Summer decomposition rates (control vs. CGS level 1 vs. CGS level 2 vs. CGS level 3)

There is a significant difference (p=0.0002) in decomposition rates between the summer pigs (control; CGS levels 1-3).

The significance of the decomposition rates between each of the individual summer pigs (control; CGS levels 1-3), over the forecasted 1000 ADD period (actual ADD = 1101.464 ADD) is provided in Table 4.6.

Table 4.6: Multi-level mixed effect modelling comparing the decomposition rates of each of the summer burn levels (control, CGS level 1, CGS level 2; CGS level 3)

Season	Burn Levels	p-value	Significant (yes/no)
Summer	Control and CGS level 1	0.0126	Yes
	Control and CGS level 2	0.2272	No
	Control and CGS level 3	0.0592	No
	CGS level 1 and CGS level 2	0.1247	No
	CGS level 1 and CGS level 3	<0.0001	Yes
	CGS level 2 and CGS level 3	0.0049	Yes

At the end of the data collection period (at 1203.026 ADD) the CGS level 1 pig had decomposed the most (standardized TBS = 29.1), followed by the CGS level 3 pig (standardized TBS = 27.6), then the CGS level 2 pig (standardized TBS = 24.8) and finally the unburned control (decomposed the least) (standardized TBS = 20.6) (Figure 4.9 and Appendices 8 – 11). All burned pigs were skeletonized with varying amounts of desiccated tissue adhesion. The unburned control pig was at an earlier stage of decomposition compared to the burned summer pigs (control still had desiccated tissues and desiccated skin remaining with minimal skeletal exposure of the ribs, mandible, maxilla and limbs) (Figure 4.10 and Appendices 15-18).

The decomposition of all burned summer pigs exhibited an initial rapid decomposition rate, followed by an intermediate period of slowed decomposition rate, and ended with a final increased decomposition rate (Figure 4.9 – note the two red dashed lines delineating the stages of differing decomposition rates).

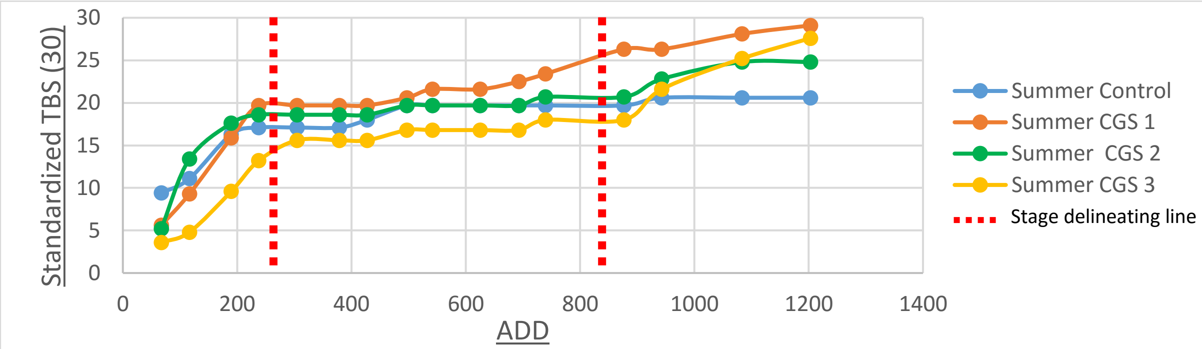

Figure 4.9: A comparison of the decomposition of the summer Control, CGS level 1, CGS level 2 and CGS level 3 pigs

Figure 4.10: A comparison of the unburned summer control pig (top left), summer CGS level 1 pig (middle left), summer CGS level 2 pig (middle right) and CGS level 3 pig (right) at the end of the data collection period (1203.026 ADD)

4.3.2 Summary

In summer there was a significant difference in the decomposition rates of the pigs, collectively. The CGS level 1 pig decomposed the furthest, followed by the CGS level 3 pig, CGS level 2 pig, and finally the unburned control.

The summer burned pigs appeared to be decomposed in three stages: an initial stage with a rapid decomposition rate, an intermediate stage with a relatively lower (or halted in winter) decomposition rate, and a final stage with a final spike with increased decomposition rates.

4.4 Seasonal differences

At the forecasted 1000 ADD observation period (1101.464 ADD) there was a significant difference ($p<0.0001$) in the decomposition rates between the winter control pig and the winter CGS level 2 pig. The winter control pig scored a higher standardized TBS of 19.7 compared to the winter CGS level 2 pig's standardized TBS of 15.5 (Figure 4.11). The winter control was in a later stage of decomposition (head and neck skin was desiccated, the torso was deflated, the skin was desiccated, and ribs were exposed). In contrast, the burned CGS level 2 pig was in an earlier stage of decomposition (the pig still being completely fleshed and in the process of deflating) (Figure 4.12 and Appendices 13-14).

There is no significant difference in decomposition rates between the summer control pig and summer CGS level 2 pig ($p=0.2272$) at the forecasted 1000 ADD. However, the summer CGS level 2 pig decomposed farther with 4.2 standardized TBS points ahead of the unburned control pig (Figure 4.11).

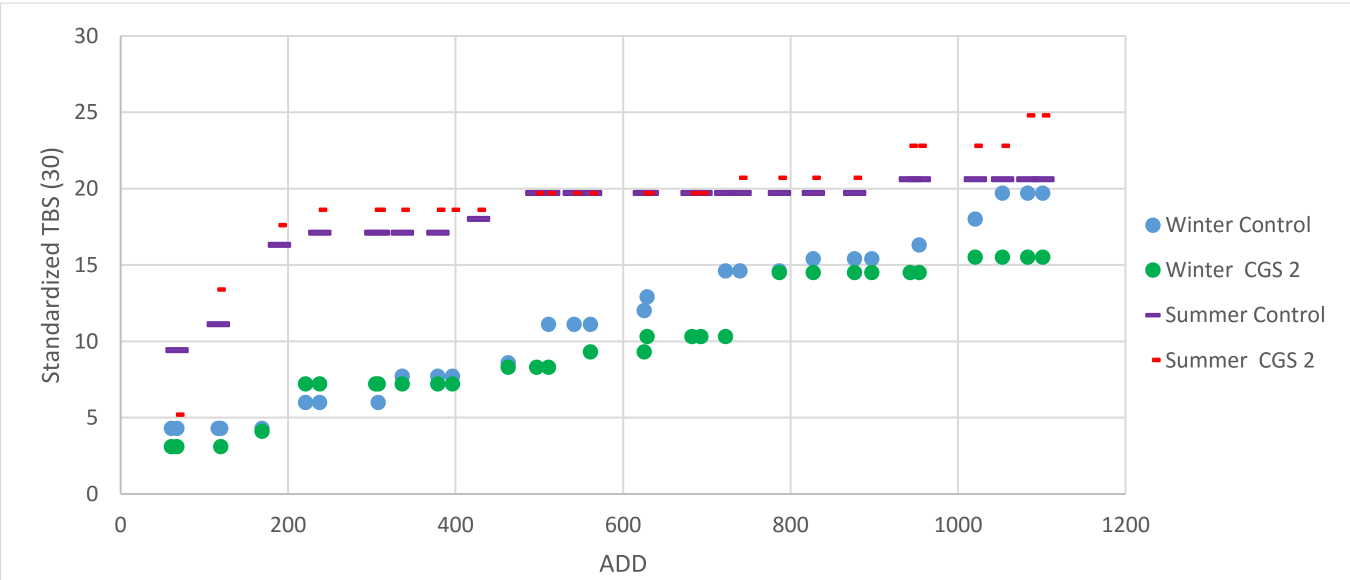

Figure 4.11: A comparison of the decomposition rates of the winter and summer control and CGS level 2 pigs

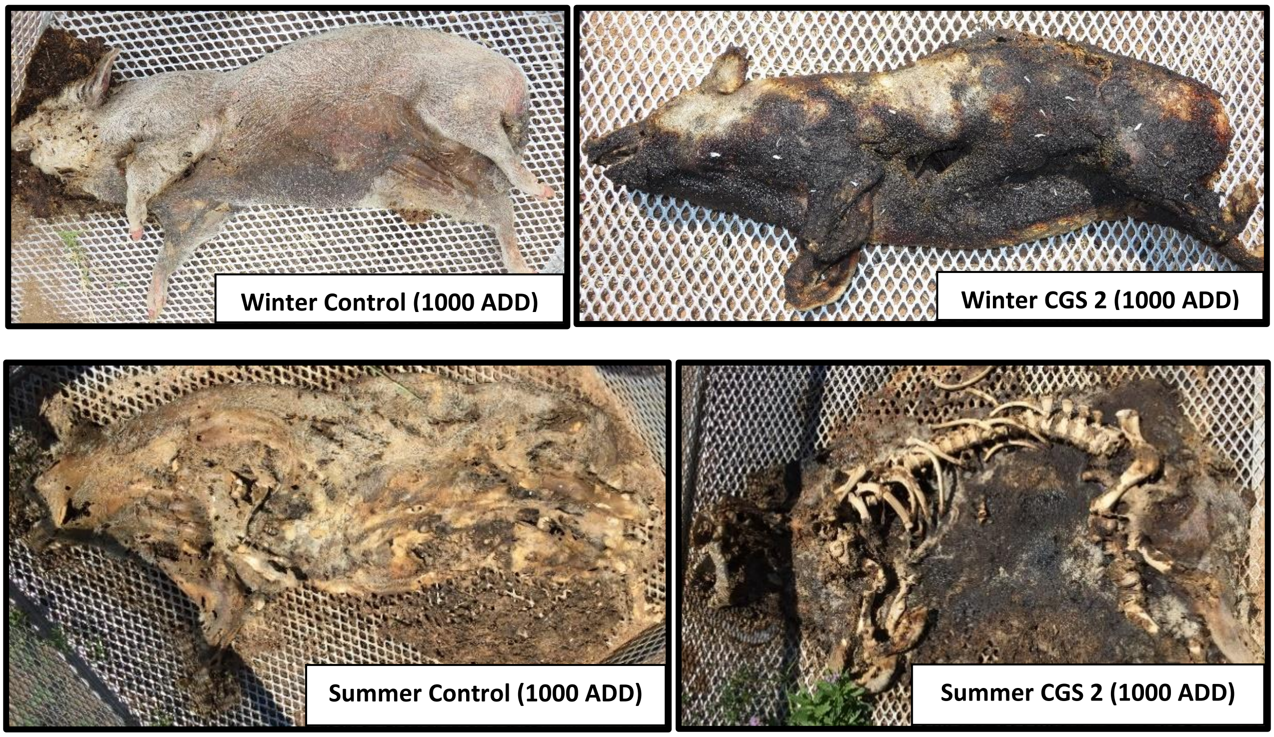

Figure 4.12: A comparison of the winter control pig and CGS level 2 pig at forecasted 1000 ADD and 2000 AD and the summer control pig and CGS level 2 pig at forecasted 1000 ADD

4.5 Decomposition variances of body regions and respective CGS levels

4.5.1 The effects of the interaction between body region and burn levels on decomposition

There is a significant interaction between the burn level and body region on the decomposition rates of the winter (control and CGS level 2) ($p<0.0001$) and summer (control, CGS levels 1-3) ($p=0.0228$) pigs.

4.5.2 The differential decomposition of body regions

There is a significant difference in the decomposition rates of the head, torso, and limbs regions in both the winter pigs (control and CGS level 2) ($p<0.0001$) and summer pigs (control and CGS level 1-3) ($p=0.0031$).

The significance of the decomposition rate differences between the body regions (head, torso, limbs) of each summer and winter pig are provided in table 4.7. Visual comparisons are provided in figures 4.13 – 4.18.

Table 4.7: Multi-level mixed effect modelling on the decomposition rates of the body regions (head; torso; limbs) of the summer and winter pigs

Pig and body regions	p-value	Significant (yes/no)
Winter control (head; torso; limbs)	<0.0001	Yes
Winter CGS level 2 (head; torso; limbs)	<0.0001	Yes
Summer Control (head; torso; limbs)	0.4235	No
Summer CGS level 1 (head; torso; limbs)	0.4547	No
Summer CGS level 2 (head; torso; limbs)	0.0027	Yes
Summer CGS level 3 (head; torso; limbs)	0.0015	Yes

There is a significant difference in the decomposition of the winter control pig's body regions ($p<0.0001$) (Table 4.1). The head region decomposed much further than the other regions, with a slight difference between the torso and limbs regions (Figure 4.13).

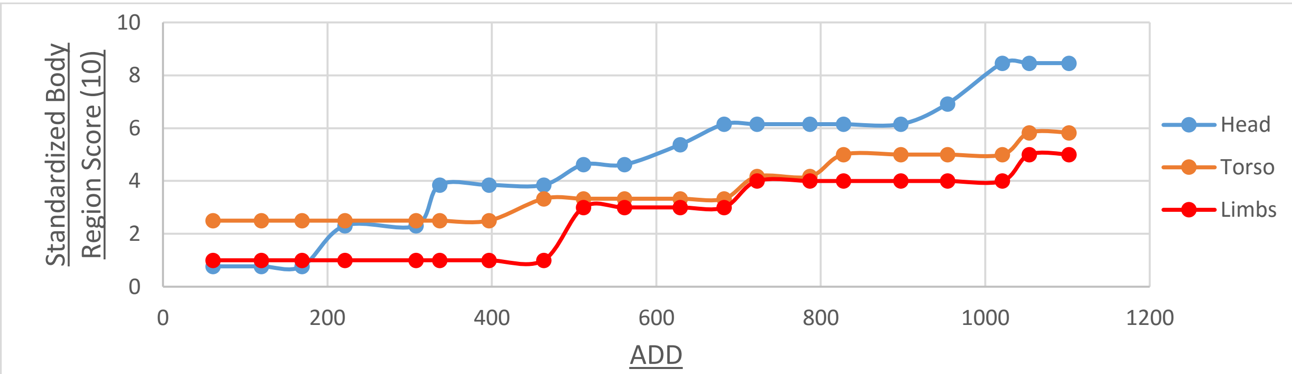

Figure 4.13: A comparison of the decomposition of the body regions in the winter control pig

There is a significant difference in the decomposition of the winter CGS level 2 pig's body regions ($p<0.0001$) (Table 4.1). The torso region decomposed much further than the other regions, with a slight difference between the head and limbs regions (Figure 4.14).

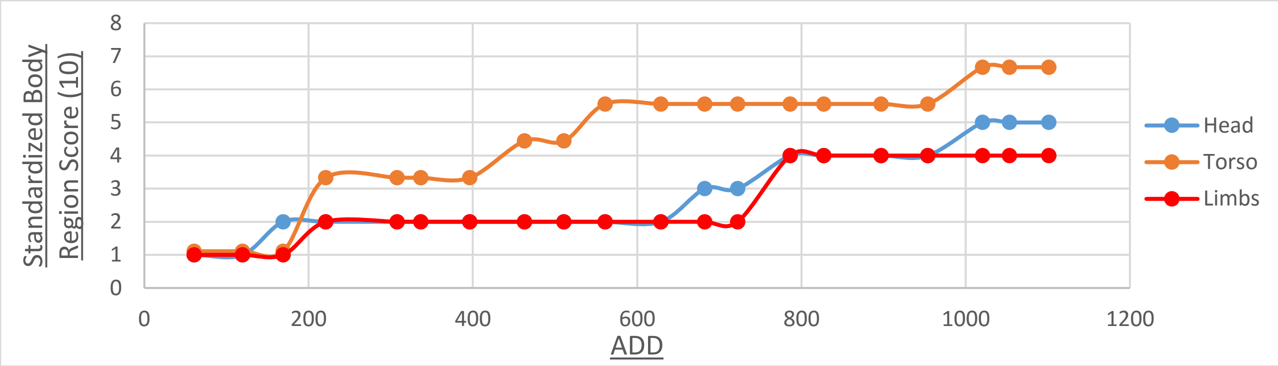

Figure 4.14: A comparison of the decomposition of the body regions in the winter CGS level 2 pig

There is no significant difference in the decomposition of the summer control pig's body regions (p=0.4235) (Table 4.1). All regions scored similarly through the decomposition process (Figure 4.15).

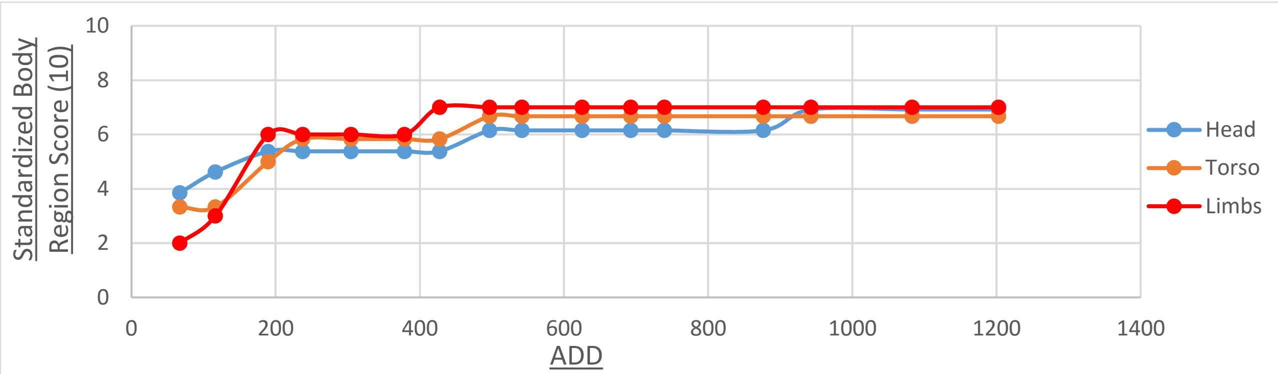

Figure 4.15: A comparison of the decomposition of the body regions in the summer control pig

There is no significant difference in the decomposition of the summer CGS level 1 pig's body regions (p=0.4547) (Table 4.1). All regions scored similarly through the decomposition process (Figure 4.16).

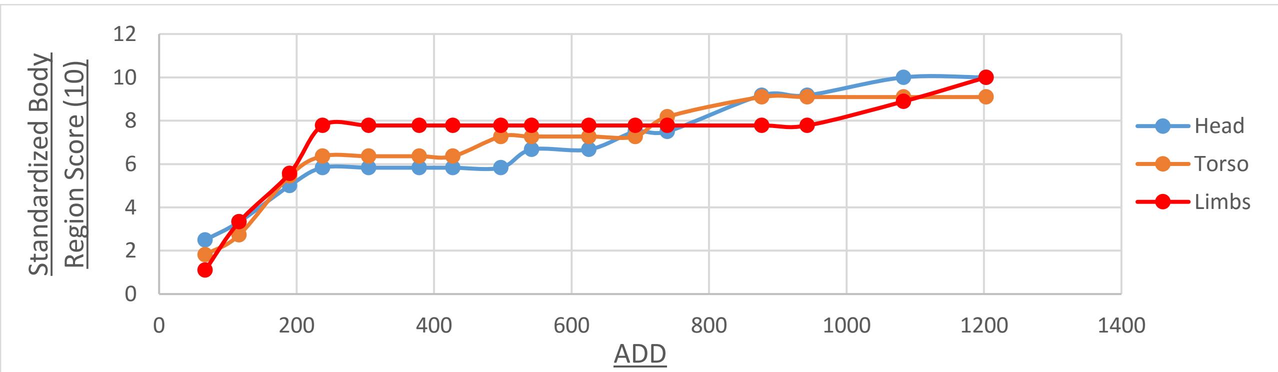

Figure 4.16: A comparison of the decomposition of the body regions in the summer CGS level 1 pig

There is a significant difference in the decomposition of the summer CGS level 2 pig's body regions (p=0.0027) (Table 4.1). The torso region generally decomposed much further than the other regions, with a little difference between the head and limbs regions (Figure 4.17).

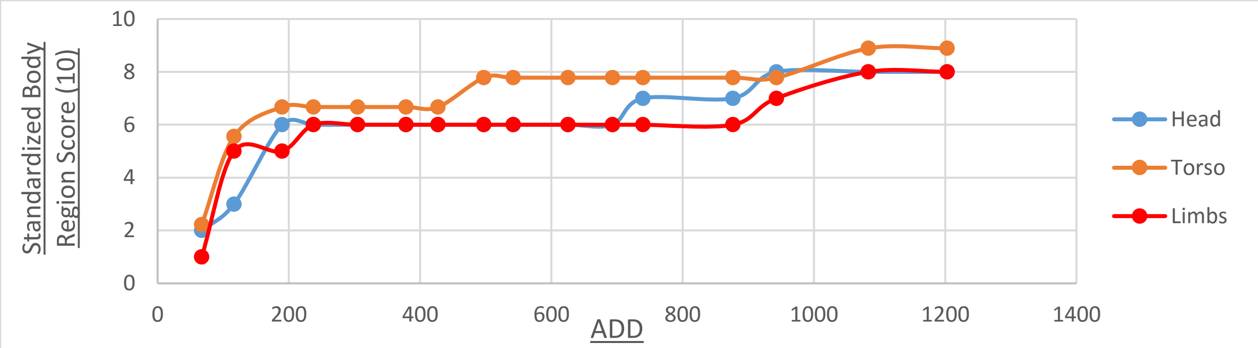

Figure 4.17: A comparison of the decomposition of the body regions in the summer CGS level 2 pig

There is a significant difference in the decomposition of the summer CGS level 3 pig's body regions (p=0.0015) (Table 4.1). The head region generally decomposed slower than the other regions, with a little difference between the head and limbs regions (Figure 4.18).

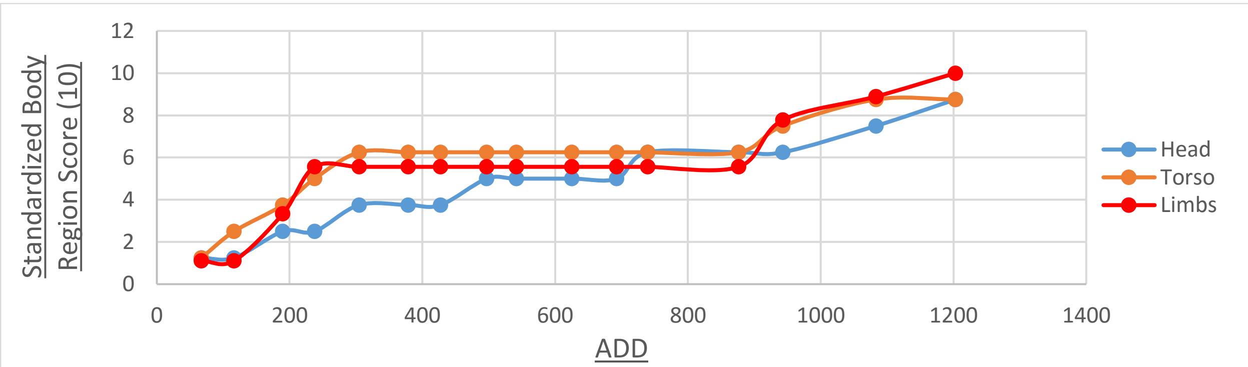

Figure 4.18: A comparison of the decomposition of the body regions in the summer CGS level 3 pig

4.5.3 The effect of burn level on body region decomposition

There is a significant difference in the decomposition rates of the burn levels in each body region in both seasonal pig samples (Table 4.8). The only exception is there is no significant difference between the unburned control and CGS level 2 on the limbs region in the winter pig sample (Table 4.8).

Table 4.8: Multi-level mixed effect modelling on the effects of the burn level (unburned, CGS level 1, CGS level 2, CGS level 3) on the decomposition of the body regions (head; torso; limbs) of the summer and winter pigs

Body Region	Burn levels	p-value	Significant (yes/no)
Head	Winter control; winter CGS level 2	<0.0001	Yes
	Summer control; Summer CGS level 1-3	<0.0001	Yes
Torso	Winter control; winter CGS level 2	0.0002	Yes
	Summer control; Summer CGS level 1-3	0.0014	Yes
Limbs	Winter control; winter CGS level 2	0.3932	No
	Summer control; Summer CGS level 1-3	0.0036	Yes

The winter control head region decomposed significantly faster than the winter CGS level 2 head region ($p<0.0001$) (Table 4.8) (Figures 4.19 and 4.20).

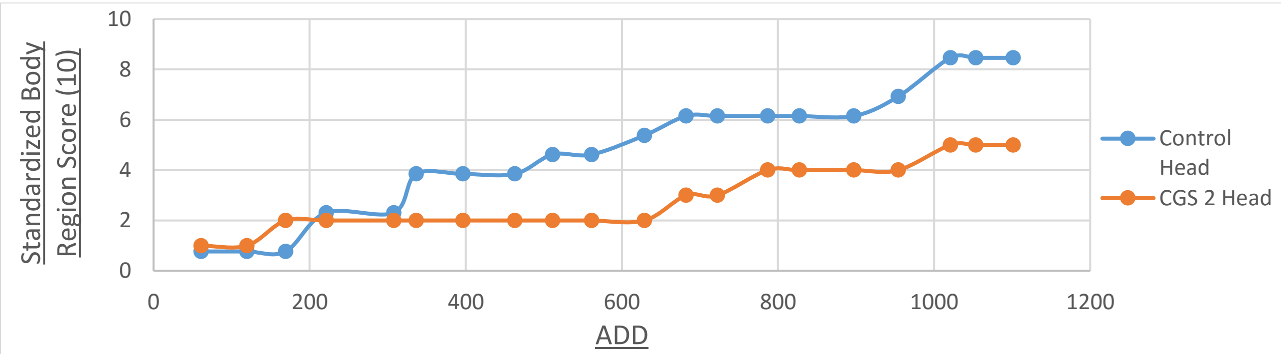

Figure 4.19: A comparison of the decomposition of the head and neck region between the winter control and CGS level 2 pigs

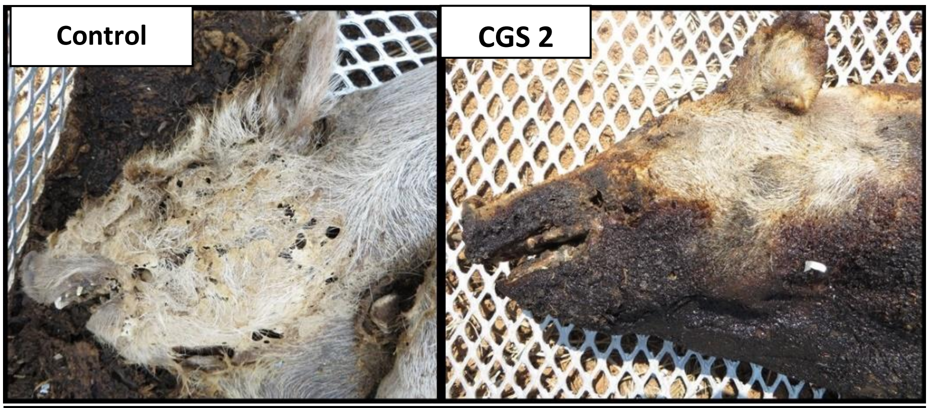

Figure 4.20: A comparison of the head and neck regions of the winter control pig and winter CGS level 2 pig at 1101.464 ADD

There is a significant difference (p=0.0002) between the decomposition rates of the winter control torso region and the winter CGS level 2 torso region (Table 4.8). The winter CGS 2 torso was generally decomposed at a greater level as it scored higher points (Figures 4.21 and 4.22).

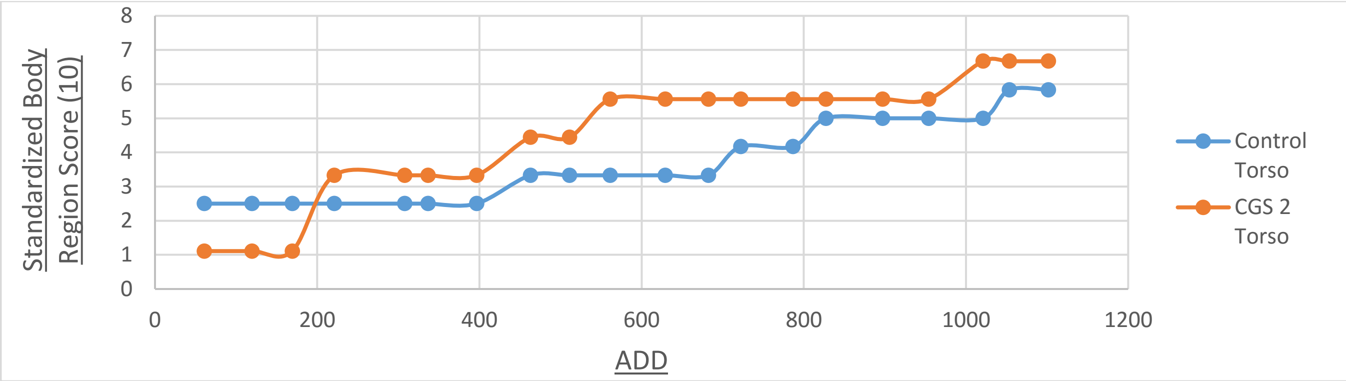

Figure 4.21: A comparison of the decomposition of the torso regions between the winter control and winter CGS level 2 pigs

Figure 4.22: A comparison of the torso regions of the winter control pig and winter CGS level 2 pig at 1101.464 ADD

There is no significant difference (p=0.3932) between the winter control limbs region and the winter CGS level 2 limbs region (Table 4.8) (Figures 4.23 and 4.24).

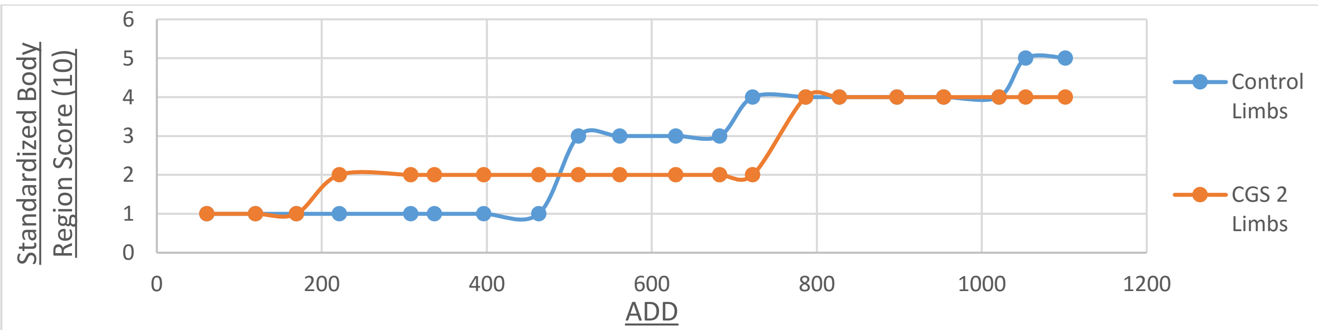

Figure 4.23: A comparison of the decomposition of the limbs region between the winter control and CGS level 2 pigs

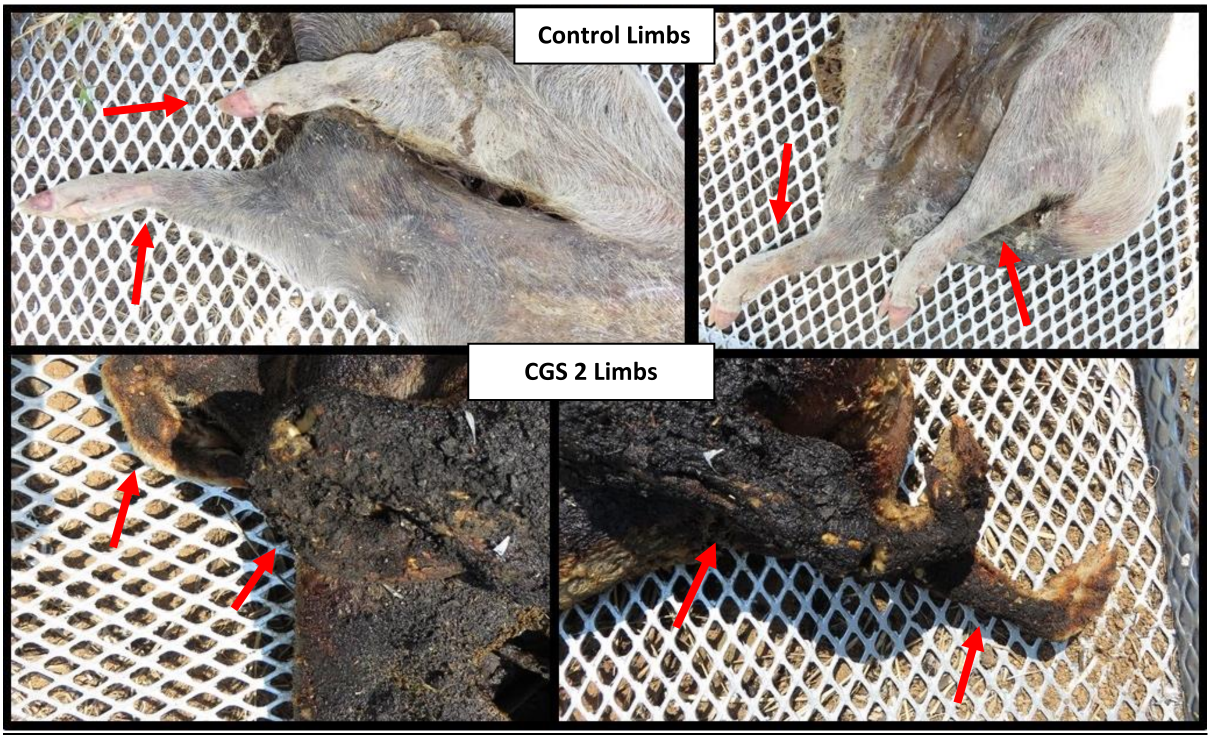

Figure 4.24: A comparison of the limbs regions (forelimbs on left and hind limbs on right – see arrows) of the winter control pig and winter CGS level 2 pig at 1101.464 ADD

There is a significant difference in the decomposition rates of the summer head regions ($p<0.0001$) (Table 4.8). The CGS level 1 pig head region decomposed the furthest, followed by the CGS level 3 pig head, then the CGS level 2 pig head, with the control pig head decomposing the slowest (Figures 4.25 and 4.26).

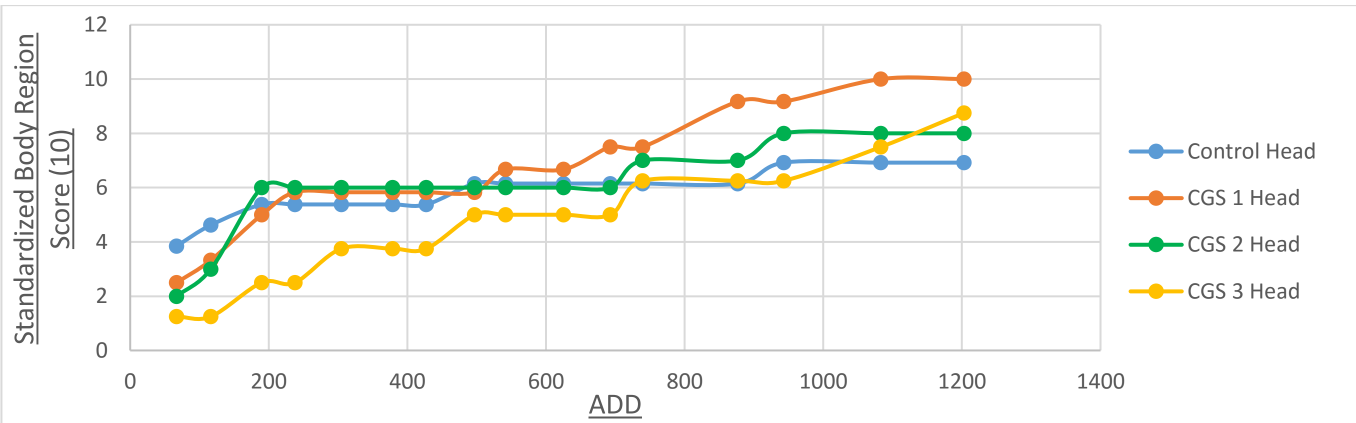

Figure 4.25: A comparison of the decomposition of the head and neck region between the summer control, CGS level 1, CGS level 2 and CGS level 3 pigs

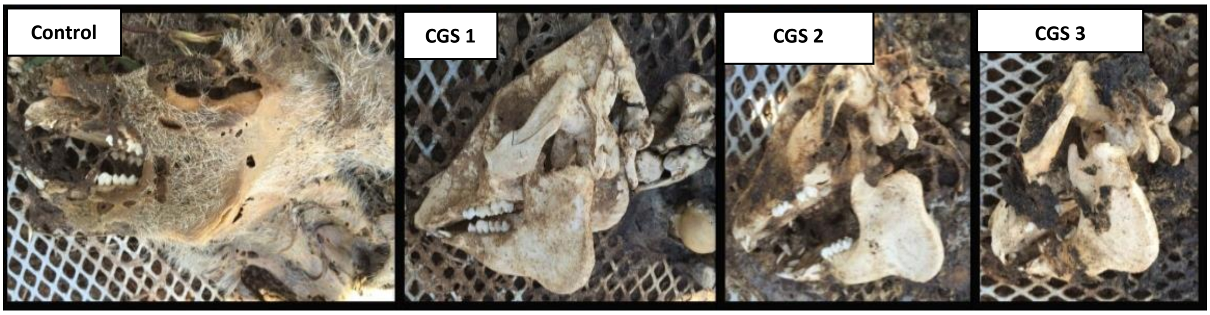

Figure 4.26: A comparison of the head and neck regions of the summer control pig, CGS level 1 pig, CGS level 2 pig, and CGS level 3 pig at 1203.026 ADD

There is a significant difference in the decomposition rates of the summer torso regions (p=0.0014) (Table 4.8). The control pig torso region decomposed much slower than the burned pigs and remained unchanged from 497.1095 ADD until the end of the data collection period (with a SBRS of 6.25) (Figures 4.27 and 4.28).

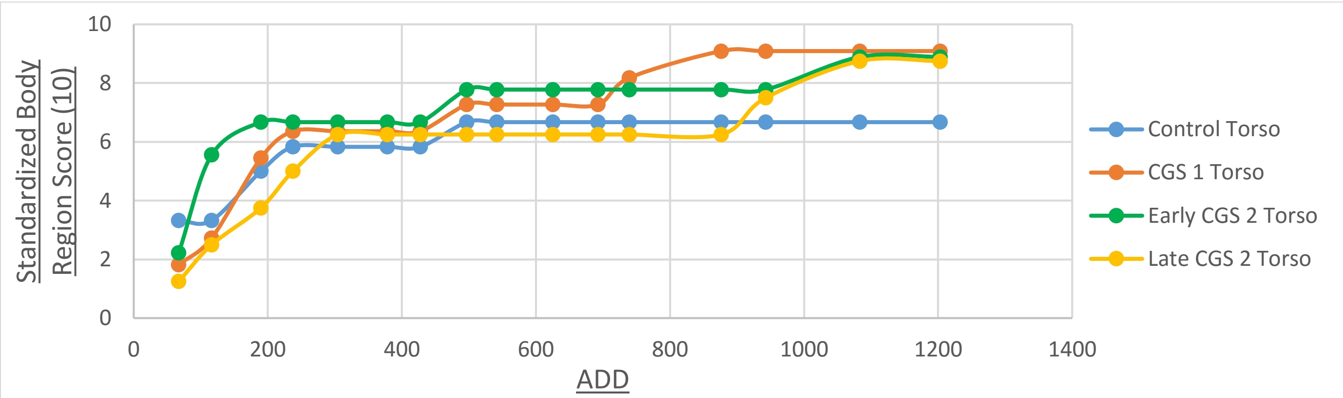

Figure 4.27: A comparison of the decomposition of the torso region between the summer control, CGS level 1, CGS level 2 and CGS level 3 pigs

Figure 4.28: A comparison of the torso regions of the summer control pig, CGS level 1 pig, CGS level 2 pig, and CGS level 3 pig (at 1203.026 ADD)

There is a significant difference in the decomposition rates of the summer limbs regions (p=0.0036) (Table 4.8). For the majority of the decomposition process the CGS level 1 pig limbs region consistently decomposed the furthest, followed by the control pig limbs, then the CGS level 2 pig limbs, with the CGS level 3 pig limbs decomposing the slowest. After 876.616 ADD there was a drastic change in the decomposition rates of the CGS level 2 and CGS level 3 pigs' limbs. At the end of the observation period the CGS level 1 and CGS level 3 pigs' limbs were the most decomposed, followed by the CGS level 2 pig's limbs, with the control pig's limbs the least decomposed. The control pig's limbs remained unchanged from 427.4295 ADD until the end of the observation period (Figures 4.29 and 4.30).

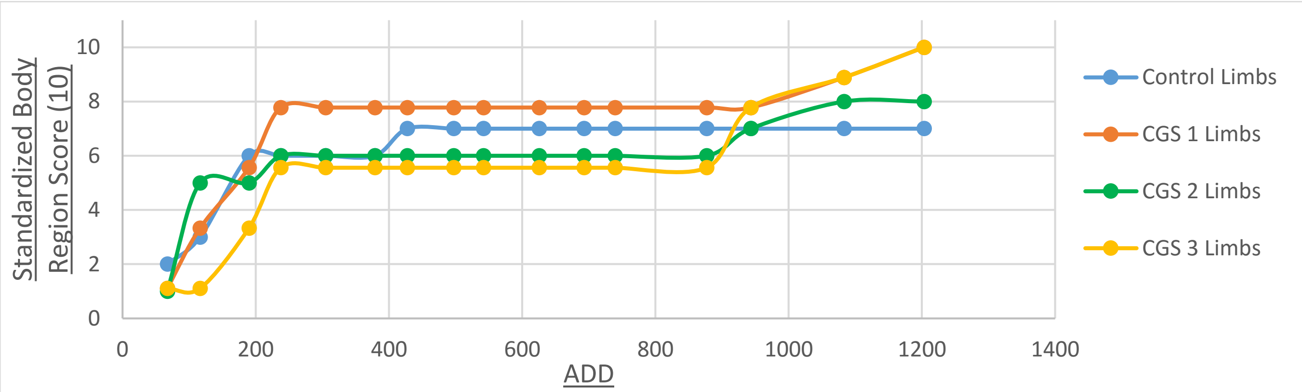

Figure 4.29: A comparison of the decomposition of the limbs region between the summer control, CGS level 1, CGS level 2 and CGS level 3 pigs

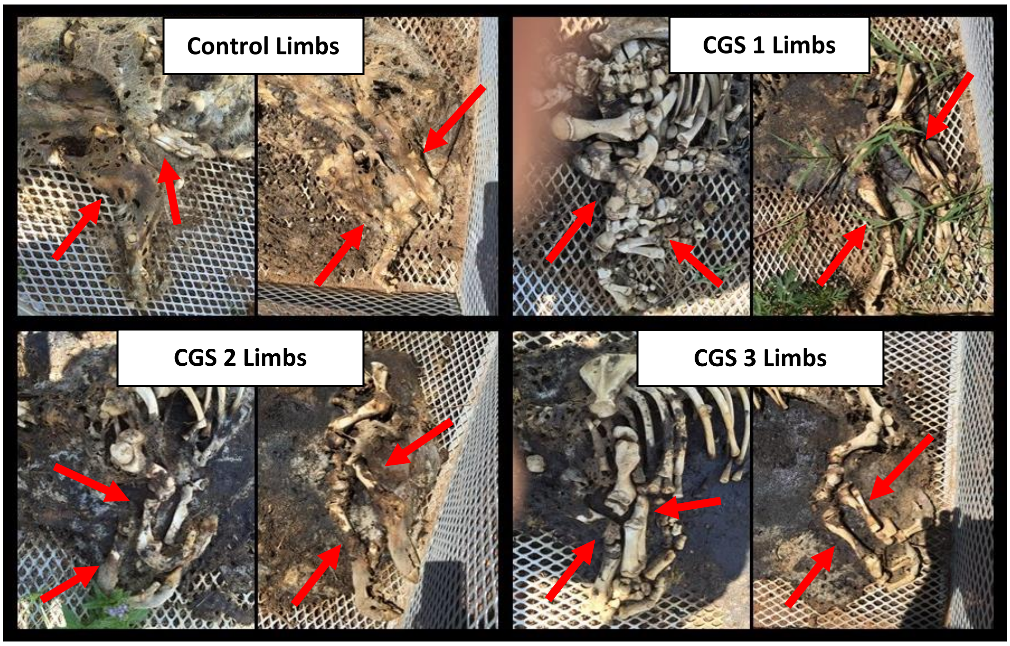

Figure 4.30: A comparison of the limbs regions (fore- and hind-limbs – see arrows) of the summer control pig, CGS level 1 pig, CGS level 2 pig, and CGS level 3 pig (at 1203.026 ADD)

4.6 Summary of results

1. Unique body scoring systems were developed for bodies individually burned to levels CGS level 1 (termed: CGS 1 TBS), CGS level 2 (termed: CGS 2 TBS) and CGS level 3 (termed: CGS 3 TBS). The charred body scale and each unique body scoring systems (CGS 1 TBS; CGS 2 TBS; CGS 3 TBS) have high average absolute measures correlation coefficients. The individual absolute measures correlation coefficients were higher in each unique body scoring systems than the charred body scale method. There is poor agreement between each of the unique body scoring systems and the CBS method. The CBS method consistently overestimated decomposition scores.
2. Abnormal signs of bloating occurred in the burned pigs, namely dorsal bloating of the summer CGS level 1 pig (exhibited as a large back hump), expulsion of the snout disk in the early CGS level 2 pig, very minimal to no visible bloating signs in the abdomens of all burned pigs (excluding the summer CGS level 1 pig), and the preservation or complete halting of decomposition of the winter early CGS level 2 pig.
3. In summer there was a significant difference in the decomposition rates of the pigs, collectively. The CGS level 1 pig decomposed the furthest, followed by the CGS level 3 pig, CGS level 2 pig, and finally the unburned control. The summer burned pigs appeared to be decomposed in three stages: an initial stage with a rapid decomposition rate, an intermediate stage with a relatively lower (or halted in winter) decomposition rate, and a final stage with a final spike with increased decomposition rates.
4. The winter CGS level 2 pig decomposed significantly slower than the winter control, as opposed to the summer CGS level 2 pig which decomposed farther than the summer control.
5. There is a significant interaction between the burn level and body region on the decomposition rates. There is a significant difference in the decomposition rates of the head, torso, and limbs regions with no single region consistently decomposing faster than other regions. There is a significant difference in the decomposition rates of the burn levels in each body region with the CGS level 3 decomposing fastest, followed by the CGS level 3, then the CGS level 2, and finally the control decomposing slowest in all body regions.

Chapter 5: Discussion

5.1 Body scoring systems

5.1.1 Interobserver error of CBS and unique burn level TBS methods

Both the charred body scale method and the unique burn level methods developed by this study (CGS 1 TBS; CGS 2 TBS; CGS 3 TBS) demonstrated ‘almost perfect’ agreement (all kappa statistics > 0.9) between observers for *average* absolute measures in each of the body regions (total, head and neck, torso, limbs) and in each total body score (Table 4.4) (Landis & Koch 1977). Each of the unique burn level methods did however have higher kappa scores for each of their total body scores and in each body region than the CBS method (Table 4.4), therefore there is a lower interobserver error in the unique burn level method than in the CBS method (Landis & Koch 1977).

Since the *average* absolute measures for both methods showed almost perfect agreement, it means that when many people use either method (the CGS method or the unique burn level methods developed by this study), the overall scores of the group will be similar or agree with each other and is therefore a reliable method to be used by groups of people (Shrout & Fleiss 1979).

Each of the unique burn level methods all scored higher *individual* absolute measures for the total body scores and each of the body regions than the CBS method (Table 4.5). The only exception was the CGS 3 TBS head and neck region scores which had a kappa statistic 0.01 less than the CBS method for the same region. The CGS 1 TBS and CGS 2 TBS methods demonstrated ‘almost perfect’ agreement between observers for the *individual* absolute measures for all body regions (Landis & Koch 1977).

The CGS 3 TBS method demonstrated *individual* average measures with ‘almost perfect’ agreement in the total body scores and torso scores, and ‘substantial’ agreement in the head and neck scores and limbs scores (Table 4.5). The CBS method demonstrated *individual* average measures with ‘almost perfect’ agreement in the total body scores only, and ‘substantial’ agreement in the scores of each of the body regions (Landis & Koch 1977).

The *individual* absolute measures for the unique burn level methods were generally higher than the CBS in this study. This means that an individual who uses the unique burn level method will assign more accurate scores than an individual who uses the CBS method (Shrout & Fleiss 1979).

The limb region scores in the CBS method and all of the unique burn level methods each demonstrated lower kappa statistics than the other regions (Table 4.5), which suggests that there is a greater variability in the limbs scores and therefore a greater level of subjectivity in the scoring of that region (Landis & Koch 1977).

Since the average absolute measures and individual absolute measures of the unique burn level TBS methods demonstrated lower levels of interobserver error, they are more reliable methods for scoring burned remains than the CBS method developed by Gruenthal, Moffatt & Simmons (2012) (Shrout & Fleiss 1979).

5.1.2 Agreement between the CBS method and unique burn level TBS methods

The Bland-Altman plots compared the CBS method scores to each of the unique burn level TBS method scores (Figures 4.1 - 4.3). All of the Bland-Altman plots indicated a poor agreement between the CBS scores and the unique burn level TBS scores (CGS 1 TBS, CGS 2 TBS, CGS 3 TBS). In all of the Bland-Altman plots the means indicated that the CBS method overestimated the decomposition scores. In all of the Bland-Altman plots the 95 % limits of agreement indicated that in 95% of the time the CBS method will disagree with the unique burn level TBS scores (CGS 1 TBS, CGS 2 TBS, CGS 3 TBS) with a large range that is "clinically unacceptable" (Bland & Altman 1986). In forensic practice the large ranges in assigned scores could indicate that the body is in a different stage of decomposition than it really is. This would have significant effects of postmortem intervals and results in an incorrect PMI estimation that is, most likely, much longer than is true. CBS is not an accurate measure of decomposition in bodies fully burned to CGS levels 1-3.

The CBS system is not appropriate for scoring burned remains since it was developed on cases that were burned differentially, with head and limb regions burned to a CGS level 1 and the torso region burned to a CGS level 2 (Gruenthal, Moffatt & Simmons 2012). The rates and patterns of decomposition observed in this study are noted to be different between the various CGS levels, and thus a scoring method, such as the CBS scoring method, can only be accurately used on cases similar to the sample used to develop the CBS methods. This highlights the difficulty of scoring burned remains due to the unique contexts and resulting char trauma of burned remains cases.

The uniquely developed scoring system for each CGS level developed by this study is a better measure for the differential decomposition of each individual CGS level. The CGS level scoring systems developed by this study are limited in their use to cases where all body regions are burned to the same CGS level. Since this is not always the case in the forensic setting (Fanton *et al.* 2006; Tümer et al. 2012) there is a need for a more universal scoring system that can be applied to all burn cases. This universal scoring system needs to account for all CGS levels of burns in each of the body regions.

Finding an accurate and robust body scoring system for burned remains (inclusive of all charring variations) is necessary for the accurate estimation of PMI. The comparison of the CBS and unique CGS level scoring systems in this study highlights the difficulty of developing an accurate, universal scoring system for burned remains. Once an accurate scoring system has been developed, an equation for

PMI estimation can be developed. Current PMI estimation calculations based on body scoring systems (Megyesi *et al.* 2005; Myburgh et al. 2013) are not designed for use on burned remains and should not be used in such cases (the only exception appearing to be the use of TBS on bodies burned to an CGS level 2). A universal PMI formula applicable to all forensic decomposition cases, inclusive of all taphonomic variables, has not yet been developed but has been attempted (Vass 2011). It is highly unlikely that such a method can be accurately developed (Cockle & Bell 2015). PMI equations for specific variations and regions, however, are of importance and do need to be further pursued and refined.

Until such a robust method of scoring is developed, it is suggested that these unique burn level TBS scoring methods be used in cases where the burn level is discernable.

5.2 Decomposition patterns

5.2.1 Decomposition patterns of the controls

There have been extensive studies into the patterns of decomposition of bodies unaltered by fire or thermal influence (Rodriguez & Bass 1983, Galloway et al. 1989, Mann *et al.* 1990, Ambach *et al.* 1992, Shean *et al.* 1993, Komar 1998, Fiedler & Graw 2003, Forbes et al. 2004, Weitzel 2005, Adlam & Simmons 2007, Sharonowski, Walker & Anderson 2008, Fitzgerald & Oxenham 2009, Michaud & Moreau 2011, Parks 2011) but no published studies dedicated to the description of decomposition patterns in burned remains. These typical patterns and stage progressions (livor mortis, marbling, skin slippage, bloat, moist decomposition, skeletal exposure, desiccation and skeletonization) were exhibited in both the winter and summer control pigs of this study with no notable variance. This uniform decomposition of the control pigs means that the variance of the decomposition patterns exhibited by the burned experimental pigs can be attributed to the CGS level burns they received and not due to any other variable.

5.2.2 Decomposition pattern variations common to the burned pigs

All the burned experimental pigs exhibited decomposition pattern variances, some that were common variances in all the burned case and some that were unique to their respective CGS level. The common variances included deep splits in the flesh of the caudal/back area of the pigs, abnormal bloating and intestinal herniation.

Splitting of charred skin is a common event in burned cases, especially in bodies that have been disturbed and moved post-burning (Shepherd 2003), however the deep splits in the flesh of the back are not typical as they were not superficial cracks in the dermal layers only. Each of the burned pigs exhibited skin splitting in the area of the back along the cranio-caudal axis lateral to the spinal column. The skin splitting was followed by deep splits in the underlying flesh and muscle within the boarder of the split skin. The only exception noted was with the summer CGS level 1 pig which exhibited back bloating in the form of a hump along the back skin split. This specific finding is unique and has not been previously mentioned in forensic taphonomic or entomological literature describing burned remains and their subsequent decomposition (Avila & Goff 1998; Gruenthal *et al.* 2012). Decomposition studies on burned remains is novel therefore, this is a phenomenon that requires further exploration.

All burned pigs, with the exception of the summer CGS level 1 pig, displayed very minimal or no signs of bloat. Typically, very slight, almost imperceptible extension of the neck could be observed in the area of the neck. This slight extension was only discerned through comparisons of photos of the neck overtime. The only sign of stage progression from the bloat stage to the post-bloat stages was the collapse of the neck and abdomen. The reasons for the collapse of the neck and abdomen are unclear, but could be attributed to either a loss of accumulated decomposition gases or loss of biomass due to the internal decomposition of viscera or a combination of both. Further studies need to be performed to determine the true cause. The summer CGS level 3 pig exhibited no signs of bloat at all.

A number of reasons could explain why no bloat stage was viewed in the summer CGS level 3 pig. Firstly, the lack of observed bloating could potentially be attributed to the denaturation of proteins by heat causing the tissues to lose their elasticity (Sauko & Knight 2004). A lack of tissue elasticity will hide the conventional bloating signs caused by gas accumulation. The only observational method of determining progression to the post-bloat stages would be the collapse of the neck and abdomen. This viewed collapse could be due to the loss of structural integrity of internal tissues due to internal decomposition. Secondly, the bloat stage was very short in the summer burned pigs (the onset of the post-bloat stages was noted by the collapse of the neck and/or abdomen). The bloat stage has been observed to be shorter in burned cases (Avila & Goff 1998) and this is not unique to this study. Thus, the rapid onset and completion of the bloating process could have been missed between observation intervals. Thirdly, the cracking and splitting of skin and flesh caused by charring could have led to the early release of accumulated bacterial gasses resulting in bloating (Avila & Goff 1998). Hence the bloating stage could have been either shortened or completely skipped.

All the summer pigs (including the control, but excluding the CGS level 3 pig) exhibited intestinal herniation, whereas neither of the winter pigs exhibited herniation. Gruenthal *et al.* (2012) deduced that intestinal herniation is due to structural damage to the abdominal wall by charring. Gruenthal *et al.* (2012) noted intestinal herniation in 65% of all their burned carcasses with the onset beginning at

120 ADD with most cases peaking between 200 and 267 ADD. This study noted intestinal herniation earlier at 60.7155 ADD (CGS level 2 pig) and 119.4755 ADD (CGS level 1 pig). This earlier herniation noted in this study could be due to higher daily temperatures experienced at the Frankenwald research site compared to the TRACES (Taphonomic Research in Anthropology: Centre for Experimental Studies) (Cross et al. 2010) site in England used by Gruenthal *et al.* (2012). Gruenthal *et al.* (2012) also deduced that intestinal herniation is a hallmark of the post-bloat stage. In this study, however, intestinal herniation could be a sign that the bloat stage was in progress. This can be said since herniation was noted at earlier ADDs and herniation in the summer control was concurrent with other bloat stage criteria (neck and abdominal extension and the pig rolled onto its back due to bloating).

5.2.3 Decomposition pattern variations unique to CGS level

The summer CGS level 1 pig exhibited abnormal bloating at 116.4455 ADD. Bloating, which usually presents as distention of the abdomen, was exhibited dorsally by forming a large back hump (Figures 4.6). This hump appeared between the split skin that ran along the back along the cranio-caudal axis (Figure 4.7). It is possible that there was greater structural damage to the back than the abdominal walls since the back had a greater surface area exposed directly to the coals during burning than the surface area of the abdomen. This could have caused the resulting bloating and distention of the posterior walls of the back rather than the abdominal walls. This is unlikely though since the CGS level 1 pig only experienced blistering of the skin with no externally visible alterations that could account for this abnormal occurrence and all the pigs had their backs exposed to a greater degree to the coals than the abdomen. It is more likely that this was a unique phenomenon isolated to this individual case since no mention of similar cases has been found in the literature. Further research is required to determine if this is an isolated case or not.

In the summer CGS level 2, the cartilaginous snout disk was forcefully expelled from the nose at 67.1615 ADD (Figure 4.8) potentially by built up pressure caused by accumulating putrefactive gasses. As previously stated the bloat stage in the burned pigs was highly irregular and potentially restricted by the thermally modified tissues (loss of elasticity) of the abdominal walls. Tissue fluid purge is a common occurrence whereby gas formation in the chest causes an increase in pressure resulting in the decomposition fluids of the lungs and trachea to be expelled from the mouth and nose (Saukko & Knight 2004). It is hypothesized that the cause of the pig snout expulsion could be due to the pressure build-up of internal decomposition gasses escaping from a weakened anatomical area due to fire damage or modification. This too is a unique case with no equal noted in published literature that requires further research to positively determine the cause. This is a phenomenon that would unlikely have an equivalent in a human forensic context.

5.2.4 Other observed patterns attributed to burning and decomposition

All burned pigs exhibited splitting of the skin at the limb joints after being manually moved to their cages. The skin slippage did not occur during burning or charring. Although skin splitting all over the body is a general sign of decomposition, it is uniquely a sign of being moved if observed soon after being burned. This could potentially be used by medico-legal investigators as a sign of post-fire evidence tampering and body relocation in suspected criminal burning cases (Aggrawal 2014).

Tissue fluid purge from the noses and mouths of the pigs caused the underlying soil to darken, forming a depression in soil that remained unaltered thereafter. This soil stain is caused by an alteration in the soil pH initiated by the volatile fatty acids in the tissue fluid purge. Surrounding vegetation was also affected by the change in pH leading to a darkening of the vegetation, and even the death of the surrounding vegetation. Such an artifact may also persist up to a year (Tersigni-Tarrant & Shirley 2012) and could assist forensic investigators in the detection of the area where a body may have decomposed (if a body is suspected to have been moved or disturbed).

It is necessary to be aware of the deep lacerations formed postmortem and post-burning in the backs/caudal areas of the burned pigs. If such decomposition changes are exhibited in human bodies as well, it is necessary for forensic investigators to be aware of such artifacts so as not to misidentify them as perimortem blunt or sharp force trauma (Aggrawal 2014).

5.3 Decomposition rates

Considering all previous published research on burned bodies, only one, UK study has focused primarily on the decomposition rates of burned bodies, using a pig model (Gruenthal *et al.* 2012). Additionally, there are two other studies (a Malaysian study and a Hawaiian study) that have briefly touched on the subject. These are entomological studies on the arthropod succession patterns on burnt pig carrion (Avila & Goff 1998; Chin et al. 2008). These two studies simply make passing reference to the decomposition rates of their pig samples and each use different methods to track the decomposition rate.

Gruenthal *et al.* (2012) burned pigs differentially (head, neck and limbs received CGS level 1 burning and torsos received CGS level 2 burning) in their study. Results from their study found that although charring produced the initial appearance of more advanced decomposition, the rate did not differ from uncharred remains.

Unlike the study by Gruenthal *et al.* (2012), which looked at pigs burned with body regions burned to different CGS levels, the present study looked at pigs burned entirely to one CGS burn level. This allowed for a more in-depth look at the effect of each individual burn on soft tissue decomposition rate.

5.3.1 Decomposition of CGS level 1, CGS level 2, and CGS level 3 burns

Overall, there was a significant difference in the decomposition rates between the pigs with different burn levels. These rates affected the level of decomposition each pig reached at the end of the observation period. The CGS level 1 pig decomposed the furthest (standardized TBS = 27.1), followed by the CGS level 3 pig (standardized TBS = 27.6), then the CGS level 2 pig (standardized TBS = 24.8), and the unburned control decomposed the least (standardized TBS = 20.6). This is contrary to the findings by Gruenthal *et al.* (2012), who found that there was no significant difference in the decomposition rates between their unburned pigs and their burned pigs. The difference in results could be accounted for by the difference in the way Gruenthal *et al.* (2012) burned their pigs. The present study looked at pigs burned completely to a single burn level, hence the decomposition rates in this study can be attributed to a single burn level. Gruenthal *et al.* (2012) did not account for the effect of the interaction between various burn levels on each of their pigs. Avila and Goff (1998) observed that differences in regional location (in Hawaii) caused a difference in the decomposition rate of burned pigs, therefore this could potentially also account for the differences between this study and that by Gruenthal *et al.* (2012). It is suggested that this study be reproduced in other regions in South Africa to determine if regional differences do affect the charred decomposition rate as was observed by Avila and Goff (1998).

The CGS level 1 pig decomposed significantly faster than the unburned control pig, therefore, light charring increases the decomposition rate. From early on the CGS level 1 pig surpassed the other pigs in decomposition rates and constantly scored higher than the others. Charring of a CGS level 1 resulted in the increased release of body fluids and olfactory attractants that attract arthropods and oviposition more rapidly. The cracks in the charred skin also serve to increase the number of oviposition sites (Avila & Goff 1998; Gruenthal *et al.* 2012). This would lead to the increased maggot activity and a resultant increase in the decomposition rates of the burned remains. This pig only experienced blistering with no major thermal alteration to the underlying muscle tissue and could account for why this CGS level decomposed fastest.

The CGS level 2 pig had a significantly overall slower decomposition rate than the CGS 3 pig and no significant difference in decomposition rate to the unburned control pig. Although there is no significant difference in the overall decomposition rates between the CGS 2 pig and control pig, the CGS level 2 pig did present signs of more advanced stages of decomposition in the beginning and end of the decomposition process (Figure 4.9). Therefore, the CGS level 2 pig started at a later decomposition stage, proceeded to decompose at a similar overall rate as the control pig, but ended at a later stage of decomposition. A CGS level 2 burn therefore may not have a significant effect of the overall decomposition rate, but it does result in an earlier presentation of decomposition stages.

The CGS level 3 pig decomposed significantly slower than the CGS level 1 pig, significantly faster than the CGS level 2 pig, and had no significant difference in overall decomposition rate to the unburned control pig (at the 5% level of significance). The CGS level 3 pig consistently scored lower than all the other pigs for the first 876.616 ADD (Figure 4.9). Thereafter there was a rapid increase in the decomposition rate in this pig. This final increase in decomposition rate resulted in an overall higher decomposition rate and second furthest final standardized TBS score (Figure 4.9) which could be misleading if viewed in isolation. The reason for the initially slower decomposition progression may be due to the heavy char resulting from the CGS level burn (which had fewer skin cracks) which initially protected the pig from arthropods. As the pig decomposed the heavy char flaked off which caused or revealed flesh cracks. The delayed exposure of flesh cracks led to increased arthropod oviposition and the resultant decomposition rate spike sites (Avila & Goff 1998; Gruenthal *et al.* 2012).

The results of this study indicated that thermal alteration, in any degree, alters the decomposition rate and stage progression. Forensic investigators need to be aware of these effects particularly when determining a PMI. A number of variables in the burning process and time of year must all be taken into consideration.

5.3.2 Decomposition stages defined by changes in decomposition rate

Early forensic decomposition studies described the decomposition process as delineated decomposition stages (Rodriguez & Bass 1983; Galloway et al. 1989). These studies' methods have persisted to the present and can be divided into taphonomic studies, focusing on decomposition stages (Weitzel 2005; Heaton et al. 2010; Michaud & Moreau 2011; Parks 2011) and entomological studies, focusing on decomposition stages (Sharanowski *et al.* 2008; Voss *et al.* 2009; Anderson 2011). There has been a shift in the manner of describing decomposition the last few years towards viewing the decomposition process as a continuum (Megyesi *et al.* 2005; Fitzgerald & Oxenham 2009; Simmons *et al.* 2010). These studies have begun to describe decomposition numerically by means of body scoring systems (Megyesi *et al.* 2005; Simmons *et al.* 2010) and degree of decomposition indexes (Fitzgerald & Oxenham 2009). Michaud and Moreau (2011) provided the following reasoning for the shift away from decomposition stages: firstly, entomologists view decomposition progression by the breaking points of faunal succession which do not correspond with the delineation of presently provided decomposition stages; secondly, stages are subjective and objectivity is the goal in scientific philosophy; and lastly, decomposition stages tend to only be useful in the documentation of results. These newer scoring methods have not yet entirely moved away from decomposition stages as they still use decomposition stages in their descriptive tables when assigning scores (Megyesi *et al.* 2005; Simmons *et al.* 2010).

Although there is a movement away from using stages to describe decomposition, Michaud and Moreau (2011) found that using decomposition stages is a statistically reliable method in the prediction of the decomposition process. The present study has also found evidence to suggest that unique decomposition stages can be differentiated in burned remains, however not by decomposition changes in the soft tissue but rather by delineated stages determined by differing decomposition rates.

A closer look at the progression of standardized TBS scores over ADD (Figure 4.9) indicates that the decomposition rates of all the burned pigs could be categorized into three stages: an initial stage with a rapid decomposition rate, an intermediate stage of lower rate decomposition rate, and a final spiked increase in decomposition rate (see red stage delineating lines in Figure 4.9). Gruenthal *et al.* (2012) also noted that the burned pigs in their UK study also exhibited an initial increased decomposition rate and early advanced pattern of decomposition compared to their unburned pigs. These stages of alternating decomposition rate indicate that the decomposition of burned remains cannot be viewed as a single overview from beginning of decomposition to the end of decomposition, but should rather be viewed by stages.

All previous studies in decomposition stages have defined the stages by observational changes in the soft tissues. Future studies in decomposition stages could determine if these stages of alternating decomposition rates are unique to burned remains or if they are applicable to all decomposition cases. Further studies can also be focused on determining what variables initiate the changes in the decomposition rate at the onset of each stage.

5.4 Seasonal differences

The burned winter CGS level 2 pig decomposed at a significantly slower rate than the unburned control. This finding was contrary to the summer burned pigs which all decomposed faster that the summer control or exhibited signs of more advanced stages of decomposition than the control. Many international studies on humans and pigs have definitively found that cooler temperatures slow decomposition rates (Rodriguez & Bass 1983; Galloway et al. 1989; Mann *et al.* 1990; Shean *et al.* 1993; Komar 1998; Weitzel 2005; Sharonowski, Walker & Anderson 2008). It must be noted that thermal alterations to a CGS level 2 coupled with low temperatures appear to have an even more drastic effect on delaying decomposition changes. The significant decrease in arthropod activity during the winter period, coupled with the gross morphological thermal alteration of soft tissues appears to cause the onset of mummification or preservation. A combination of heat (from flames during burning), the dry air of the winter season, cold temperatures, and thermal alteration of the tissues by charring causing desiccation of the tissues (similar to the process of fire and smoke curing) may have caused onset of mummification or decreased decomposition rate (Haglund & Sorg 1996).

Comparing the decomposition between the winter and summer CGS level 2 pigs, the summer pig exhibited earlier onset of decomposition stages. Summer months have always produced increased decomposition stage progression (Rodriguez & Bass 1983; Galloway et al. 1989; Mann *et al.* 1990; Shean *et al.* 1993; Komar 1998; Weitzel 2005; Sharonowski, Walker & Anderson 2008) and this is not any different for burned remains. Burning did not change the contrasting effects of hot and cold temperatures on decomposition stage progression, however it did exaggerate those effects as the summer CGS level 2 pig generally scored higher standardized TBS scores than the summer control and the winter CGS level 2 pig generally scored lower standardized TBS scores than the winter control pig.

5.5 Decomposition variances of body regions and respective CGS levels

Gruenthal *et al.* (2012) raised the question whether the body region or CGS level affects the decomposition rate in burned remains. They established in their UK study that the limbs and head pig regions that were burned to a CGS level 1 decomposed slower than the same regions in the unburned control pigs. Conversely, they observed that the torsos burned to a CGS level 2 decomposed faster than the unburned torsos of the controls. The present study investigated this question and examined the decomposition of individual body regions and the affect various burn levels had on body region decomposition.

There was no single, overall body region that decomposed significantly faster than the other regions in all the pigs. The torso region did decompose significantly faster than other regions in three of the six pigs: in the winter CGS level 2 pig, the summer CGS level 2 pig, and the summer CGS level 3 pig. The winter control pig differed in that the head and neck region decomposed significantly faster than the other body regions. The summer control pig and summer CGS pig showed no significant difference in the decomposition rates of their respective body regions. Since the torso region decomposed significantly faster in half of the pigs -a result also observed in the study by Gruenthal *et al.* (2012) - suggests that body region may have a variable effect on the decomposition of a body as a whole, however, there was no single body region that consistently decomposed faster in each of the bodies suggesting that the burn levels may be influencing the individual body region decomposition rates. The lack of consensus could also mean that the decomposition of individual body regions may be highly context specific and different in every case (Saukko & Knight 2004). Many human forensic cases have described bodies that exhibit the effects of different decomposition rates in different body regions. These cases exhibited different decomposition forms such as putrefaction at one region and skeletonization at another, all within the same body. The reasoning provided for these regional differences are ‘mini-environments’ that differentially affect the decomposition rate of each body region within the same body (Saukko & Knight 2004). These ‘mini-environments’ could still play a part in burned remains as well.

The CGS level had a significant effect on the decomposition rate of each body region in all pigs (with the exception of the limbs region in the summer pigs) (Table 4.8). Burning increased he rate of decomposition in the head and neck region, the torso region, and the limbs region. The effect of CGS level on regional decomposition generally mimicked the global body decomposition rate (as discussed in sections 5.5 and 5.6), with the CGS level 1 decomposing furthest, with the CGS level 3 following or equaling the CGS level 1, followed by the CGS level 2, and finally the unburned control decomposing the least in all summer body regions. This further highlights the effect that burning has of the decomposition rate and stage progression as the effects of burning of the total body is mimicked in the small body region decomposition.

Although the burn level appears to have a greater effect on individual body region decomposition that the between the body regions themselves, there is a significant interaction between the body regions (head and neck; torso; limbs) and burn levels (unburned control and CGS levels 1-3). There is a significant interaction between the body regions and burn level in the winter pigs (control and winter CGS level 2) and the summer pigs (control; CGS level 1-3). This highlights the variable nature of decomposition. Although single variables and their effect on decomposition have been studied in isolation, it is important to remember that there is a myriad of factors that interact with each other that result in the individual decomposition of individual cases (Vass 2011). Understanding individual decomposition factors and their interactions is the aim of forensic taphonomic research (Haglund & Sorg 1996).

Gruenthal *et al.* (2012) were unable to determine if body region or burn level affected overall decomposition rates because each of their pigs were all burned to differing levels. This study has provided some preliminary answers to their question. Burn level has a significant effect on body region decomposing rates, body regions decompose differentially with no single region consistently decomposing faster than others, and there is a significant interaction between burn level and body region on decomposition rates. Further research needs to be performed on individual body regions to determine which variables specifically can cause differential decomposition rates within body regions and account for the contrasting findings between the present study and that by Gruenthal *et al.* (2012).

5.6 Limitations

There are a number of limitations to this study that need to be addressed so as to define that relevance and applicability of the results of this study.

The use of pigs in this study is not an issue and is a commonly used human analogue in forensic taphonomic research, particularly in research of decomposition nature (Chin et al. 2008; Schultz 2008; Cross & Simmons 2010; Aballay *et al.* 2012; Moffatt & Simmons 2012; Myburgh et al. 2013; Matuszewski et al. 2014; Smith 2014; Zanetti *et al.* 2014; Keough et al. 2015; Martin et al. 2016). Since the study is focused on the description of the decomposition of soft tissues, the results are applicable to humans (Gruenthal *et al.* 2012). The use of pigs in decomposition studies is a limitation when decomposition rate equations are developed on pigs as these equations, used for PMI estimations, cannot be accurately used on humans (Gruenthal *et al.* 2012). This results of this study did not develop decomposition rate equations and as such are applicable in the forensic context.

Similarly, the small size of the pigs in this study do not severely impact the applicability of the results as this study is a descriptive study observing the effects of burning on decomposition rates. Small sized animals are often used and published in forensic taphonomic decomposition studies on decomposition (Aturaliya & Lukasewycz 1999; Adlam & Simmons 2007; Simmons *et al.* 2010; Anderson 2011; Troutman *et al.* 2014). The implications of the results of these types of studies are preliminary - and should be treated as such – however they do provide valuable information on the effects of variables that have not before been provided and should not be discounted. Replication studies on larger animals and human cases are always encouraged Troutman *et al.* 2014.

The sample size of this study is an important factor to consider in the application of this study's results. The small sample did not affect the results of the interobserver error studies and agreement study of the charred body scale method and the unique burn level TBS methods (CGS 1 TBS; CGS 2 TBS; CGS 3 TBS) developed by this study, for objective one (sections 4.1.1 and 4.1.2). The small sample did have an effect on the description of decomposition patterns (objective two: section 4.2) as not all differences in the patterns could be attributed purely to the burn level or individual anomalies. The statistical results provided in sections 4.3, 4.4, and 4.6 were not severely affected by the small sample size as multilevel mixed affect models allow for the testing of small samples. The small sample size also only allowed for two pigs to be representative of the winter sample. This did limit the level of testing that could be done in the winter season, however the results did differ considerably from the summer sample and thus provided valuable additional information on the interaction of not only burn levels on decomposition, but also the interaction of burn levels and temperature on decomposition. Ultimately, the small sample size of the study was dictated by the Animal Ethics Screening Committee (AESC) and was thus out of the control of the researcher. The small sample does render the results of this study was preliminary, however the results do provide information that was not previously available, particularly: the effects of various burn levels on decomposition rates and patterns, the interaction of temperature and burning on decomposition rates, and the effects of the interaction between burn level and body region on decomposition rates.

The iButtons used in this study could only have their data retrieved after the observation period concluded, therefore the South African Weather Service was relied upon to determine the observation intervals. For both the winter and summer periods there was a discrepancy between the forecast ADD intervals provided by the South African Weather Service weather station and the site ADD provided by the on-site iButtons (Appendices 4-6). As a result, the data collection did not occur at regular 50 ADD intervals as planned. This only affected the regularity of data collection and not the accuracy of the results of this study.

The preliminary results of this study provided important information on the effects of burning on decomposition rates and patterns. This is novel research that has not been studied in South Africa or internationally. As forensic investigators are made aware of these results, they will be better able to recreate postmortem events in forensic burn cases and be aware of reservations that should be made in the estimation of a postmortem interval.

5.7 Recommendations for future research

A number of limitations of this research present opportunities for further research into similar studies on the decomposition of burned remains.

1. Obtaining pigs for this study proved incredibly difficult and expensive which limited the sample size of this study. This leaves room for the research to be repeated using a larger sample size.
2. The limited number of pigs allowed for only for two pigs to represent the winter sample, thus no CGS level 1 and CGS level 3 were represented in this study in the winter season. Future research should compare the decomposition rates of the same three summer CGS levels in winter.
3. CGS levels are too broad and do not cover the variations in between the described levels. For research purposes there is a need for the levels to be divided into more levels or sub-levels.
4. Future research needs to develop a universal total body scoring system that can be utilized in all burn cases. It needs to encompass all CGS levels for all body regions. This will assist greatly with the development of a PMI equation for all burned remains.

5. Future studies on decomposition stages can focus on the efficacy of defining decomposition stages on decomposition rate.
6. This study used unclothed pigs so future studies can look at the effects of clothing on the decomposition of burned remains.

Chapter 6: Conclusion

Many studies have been performed on the variables that affect decomposition processes, patterns and rates. Research on the effects of fire on the decomposition of remains continues to be underrepresented in forensic science literature, especially in research of a forensic taphonomic nature. The prevalence of burn mortalities and bodies with evidence of postmortem burning, in South Africa, necessitates increased awareness and focus on this topic.

This study determined that body scoring systems, developed to quantifiably describe decomposition and used in PMI estimations, need to be further developed for application in burned remains. The charred body scale system that is currently in use is not suitable for burned remains as it overestimates the level of decomposition. This study developed a decomposition body scoring system for bodies fully burned to CGS level 1, CGS level 2 and CGS level 3 burn levels. The variable nature of burning and the resultant differential charring of remains necessitate the development of a TBS system that can be applied to all burn cases. This study and that by Gruenthal *et al.* (2012) are the beginning of a number of studies that need to be performed in order to lead to the ultimate development of such a universal TBS system for all burned remains.

Burning alters the typical decomposition patterns of burned remains. Intestinal herniation and abnormal signs of bloat are common in decomposing burned remains. The minimal or absent signs of bloating in some CGS levels also require attention in the estimation of a PMI in burned remains. Abnormal decomposition events limited to individual CGS levels at the bloat stage, such as the forming of humps in the back, need to be further understood. Deep splitting of flesh and cracking of the skin are decomposition phenomenon that forensic investigators need to be made aware of as an effect of fire modification and not violent perimortem sharp/ blunt force trauma.

This study observed that burning causes an increase in the decomposition rate and earlier onset of decomposition stages in the summer, whereas in winter it slows decomposition. When comparing the decomposition rate amongst various burn levels, the decomposition rate and level is indirectly proportional to the burn level. Therefore, lower burn levels result in faster decomposition rates. The effects of charring on decomposition rates in burned remains will have an effect on the estimation of PMI, hence the traditional means of PMI estimation cannot be accurately used. Further studies need to be performed to determine what necessary adjustments must be made to PMI equations in cases of thermal alteration. The decomposition of thermally altered remains appears to proceed in three stages: an initial stage with a fast decomposition rate, an intermediate stage with a slow/retarded decomposition rate, and a late stage with a spiked increased decomposition rate.

It was also found that the variations in the decomposition rate in the different body regions is mostly due to burn level, but there is a significant interaction between burn level and body region too.

Forensic investigators, pathologists and scientists all need to be aware of these alterations in charred remains in order to more accurately reconstruct postmortem events and estimate postmortem intervals.

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Appendices

Appendix 1: Animal Ethics Screening Committee (AESC) Clearance Certificate

STRICTLY CONFIDENTIAL

ANIMAL ETHICS SCREENING COMMITTEE (AESC)

CLEARANCE CERTIFICATE NO. 2013/20/01

APPLICANT: Mr CA Keys

SCHOOL: Pathology
DEPARTMENT: Forensic Medicine
LOCATION:

PROJECT TITLE: Forensic taphonomic study into the differential decomposition rates and patterns of bodies subjected to varying degrees of burns

Number and Species

5 adult pigs (sus scrofta domesticus)

Approval was given for to the use of animals for the project described above at an AESC meeting held on 20130430. This approval remains valid until 20150429.

The use of these animals is subject to AESC guidelines for the use and care of animals, is limited to the procedures described in the application form and is subject to any additional conditions listed below:

1. **The animals must be sourced from a registered abattoir**
2. **The means of killing the animals is to be reported**
3. **The Committee wishes to know whether the animals are to be killed for the purposes of this study**
4. **Permission will be required from the Parks Authority**

Signed: ______________________ (Chairperson, AESC) Date: 6/5/13

I am satisfied that the persons listed in this application are competent to perform the procedures therein, in terms of Section 23 (1) (c) of the Veterinary and Para-Veterinary Professions Act (19 of 1982)

Signed: ______________________ (Registered Veterinarian) Date: 6/5/13

cc: Supervisor: Dr G Gordon
Director: CAS

Works 2000/lain0015/AESCCert.wps

Appendix 2: Data collection sheet 1 – observations

ADD: ____________________ **Date:** ______________________

Season: _____________________ **Time:** ______________________

Observations:

	CONTROL	CGS LEVEL 1	CGS LEVEL 2	CGS LEVEL 3
HEAD & NECK				
TORSO				
LIMBS				
COLONIZATION				
WEATHER				
DECOMPOSITION STAGE				
OTHER				

Appendix 3: Data collection sheet 2 - scores

Winter Control Pig							Winter CGS LEVEL 2 Pig																				
Total Body Score							Total Body Score							Charred Body Score							CGS LEVEL 2 Total Body Score						
Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (35)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (35)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (32)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (29)	Standardized TBS (30)
50							50							50							50						
100							100							100							100						
150							150							150							150						
Cont..							Cont..							Cont..							Cont..						

Summer Control Pig							Summer CGS LEVEL 1 Pig																				
Total Body Score							Total Body Score							Charred Body Score							CGS 1 Level Total Body Score						
Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (35)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (35)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (32)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (29)	Standardized TBS (30))
50							50							50							50						
100							100							100							100						
150							150							150							150						
Cont..							Cont..							Cont..							Cont..						

Summer CGS LEVEL 2 Pig																				
Total Body Score							Charred Body Score							CGS LEVEL 2 Total Body Score						
Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (35)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (32)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (29)	Standardized TBS (30))
50							50							50						
100							100							100						
150							150							150						
Cont..							Cont..							Cont..						

Summer CGS LEVEL 3 Pig																				
Total Body Score							Charred Body Score							CGS LEVEL 3 Total Body Score						
Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (35)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (32)	Standardized TBS (30)	Forecast ADD	Actual ADD	Head & Neck	Torso	Limbs	Total (29)	Standardized TBS (30))
50							50							50						
100							100							100						
150							150							150						
Cont..							Cont..							Cont..						

Appendix 4: Weather station forecasted accumulated-degree days

Date	Forecasted maximum temperature	Forecasted minimum temperature	Forecasted average temperature	Forecasted ADD
04 July 2014	17	10	13,5	13,5
05 July 2014	18	7	12,5	26
06 July 2014	18	3	10,5	36,5
07 July 2014	15	-2	6,5	43
08 July 2014	10	-2	4	47
09 July 2014	12	-4	4	51
10 July 2014	13	-1	6	57
11 July 2014	14	0	7	64
12 July 2014	15	4	9,5	73,5
13 July 2014	18	5	11,5	85
14 July 2014	18	4	11	96
15 July 2014	17	4	10,5	106,5
16 July 2014	18	8	13	119,5
17 July 2014	19	9	14	133,5
18 July 2014	21	7	14	147,5
19 July 2014	16	2	9	156,5
20 July 2014	18	1	9,5	166
21 July 2014	18	3	10,5	176,5
22 July 2014	17	6	11,5	188
23 July 2014	21	8	14,5	202,5
24 July 2014	22	11	16,5	219
25 July 2014	20	13	16,5	235,5
26 July 2014	17	2	9,5	245
27 July 2014	17	-1	8	253
28 July 2014	20	3	11,5	264,5
29 July 2014	16	4	10	274,5
30 July 2014	16	5	10,5	285
31 July 2014	18	7	12,5	297,5
01 August 2014	21	6	13,5	311
02 August 2014	20	8	14	325
03 August 2014	19	7	13	338
04 August 2014	18	6	12	350
05 August 2014	20	11	15,5	365,5
06 August 2014	22	9	15,5	381
07 August 2014	23	7	15	396
08 August 2014	20	5	12,5	408,5
09 August 2014	15	4	9,5	418
10 August 2014	20	5	12,5	430,5
11 August 2014	19	8	13,5	444
12 August 2014	19	5	12	456
13 August 2014	20	8	14	470
14 August 2014	24	10	17	487
15 August 2014	22	9	15,5	502,5

16 August 2014	16	10	13	515,5
17 August 2014	18	7	12,5	528
18 August 2014	20	6	13	541
19 August 2014	24	13	18,5	559,5
20 August 2014	24	11	17,5	577
21 August 2014	22	9	15,5	592,5
22 August 2014	16	3	9,5	602
23 August 2014	16	3	9,5	611,5
24 August 2014	18	5	11,5	623
25 August 2014	20	3	11,5	634,5
26 August 2014	23	5	14	648,5
27 August 2014	23	6	14,5	663
28 August 2014	23	6	14,5	677,5
29 August 2014	11	1	6	683,5
30 August 2014	15	-3	6	689,5
31 August 2014	18	1	9,5	699
01 September 2014	19	5	12	711
02 September 2014	20	4	12	723
03 September 2014	21	3	12	735
04 September 2014	21	6	13,5	748,5
05 September 2014	21	7	14	762,5
06 September 2014	24	13	18,5	781
07 September 2014	27	9	18	799
08 September 2014	29	15	22	821
09 September 2014	27	13	20	841
10 September 2014	29	15	22	863
11 September 2014	27	13	20	883
12 September 2014	29	15	22	905
13 September 2014	28	16	22	927
14 September 2014	30	14	22	949
15 September 2014	29	14	21,5	970,5
16 September 2014	28	15	21,5	992
17 September 2014	29	15	22	1014
18 September 2014	29	11	20	1034
19 September 2014	22	6	14	1048
20 September 2014	22	7	14,5	1062,5
21 September 2014	21	9	15	1077,5
22 September 2014	26	15	20,5	1098
23 September 2014	28	14	21	1119
24 September 2014	22	11	16,5	1135,5
25 September 2014	28	11	19,5	1155
26 September 2014	29	14	21,5	1176,5
27 September 2014	31	7	19	1195,5
28 September 2014	29	7	18	1213,5
29 September 2014	22	10	16	1229,5
30 September 2014	26	14	20	1249,5
01 October 2014	25	7	16	1265,5

02 October 2014	28	8	18	1283,5
03 October 2014	24	12	18	1301,5
04 October 2014	25	7	16	1317,5
05 October 2014	24	10	17	1334,5
06 October 2014	26	13	19,5	1354
07 October 2014	28	13	20,5	1374,5
08 October 2014	29	11	20	1394,5
09 October 2014	32	15	23,5	1418
10 October 2014	30	13	21,5	1439,5
11 October 2014	26	12	19	1458,5
12 October 2014	25	13	19	1477,5
13 October 2014	31	14	22,5	1500
14 October 2014	28	16	22	1522
15 October 2014	25	16	20,5	1542,5
16 October 2014	26	9	17,5	1560
17 October 2014	23	8	15,5	1575,5
18 October 2014	24	8	16	1591,5
19 October 2014	27	8	17,5	1609
20 October 2014	30	10	20	1629
21 October 2014	30	12	21	1650
22 October 2014	29	13	21	1671
23 October 2014	30	10	20	1691
24 October 2014	31	10	20,5	1711,5
25 October 2014	30	12	21	1732,5
26 October 2014	26	14	20	1752,5
27 October 2014	25	12	18,5	1771
28 October 2014	25	10	17,5	1788,5
29 October 2014	28	10	19	1807,5
30 October 2014	30	14	22	1829,5
31 October 2014	32	15	23,5	1853
01 November 2014	26	12	19	1872
02 November 2014	22	16	19	1891
03 November 2014	21	15	18	1909
04 November 2014	21	13	17	1926
05 November 2014	26	11	18,5	1944,5
06 November 2014	27	16	21,5	1966
07 November 2014	27	14	20,5	1986,5
08 November 2014	26	13	19,5	2006
09 November 2014	23	13	18	2024
10 November 2014	28	16	22	2046
11 November 2014	21	14	17,5	2063,5
12 November 2014	20	15	17,5	2081
13 November 2014	26	15	20,5	2101,5
14 November 2014	28	14	21	2122,5
15 November 2014	25	11	18	2140,5
16 November 2014	24	13	18,5	2159
17 November 2014	18	8	13	2172

18 November 2014	24	9	16,5	2188,5
19 November 2014	23	10	16,5	2205
20 November 2014	29	9	19	2224
21 November 2014	28	12	20	2244
22 November 2014	24	14	19	2263
23 November 2014	24	13	18,5	2281,5
24 November 2014	26	14	20	2301,5
25 November 2014	29	15	22	2323,5
26 November 2014	29	14	21,5	2345

Appendix 5: Winter accumulated-degree days

Date	Minimum Temperature	Maximum Temperature	Average Temperature	Winter ADD	Forecast ADD Interval
04 July 2014	0	17,68	8,84	**8,84**	
05 July 2014	0,112	18,85	9,481	**18,321**	
06 July 2014	2,372	26,232	14,302	**32,623**	
07 July 2014	0	16,663	8,3315	**40,9545**	
08 July 2014	0	18,666	9,333	**50,2875**	
09 July 2014	0	20,856	10,428	**60,7155**	50
10 July 2014	0	21,293	10,6465	**71,362**	
11 July 2014	0	21,731	10,8655	**82,2275**	
12 July 2014	0	25,732	12,866	**95,0935**	
13 July 2014	0	25,17	12,585	**107,6785**	
14 July 2014	0,112	23,482	11,797	**119,4755**	100
15 July 2014	0	26,107	13,0535	**132,529**	
16 July 2014	0	24,92	12,46	**144,989**	
17 July 2014	0,175	26,67	13,4225	**158,4115**	
18 July 2014	0	21,356	10,678	**169,0895**	150
19 July 2014	0	24,857	12,4285	**181,518**	
20 July 2014	0	25,045	12,5225	**194,0405**	
21 July 2014	0,363	25,232	12,7975	**206,838**	
22 July 2014	0,677	27,669	14,173	**221,011**	200
23 July 2014	0,803	29,106	14,9545	**235,9655**	
24 July 2014	0,803	28,919	14,861	**250,8265**	
25 July 2014	1,933	26,732	14,3325	**265,159**	
26 July 2014	0,803	25,545	13,174	**278,333**	
27 July 2014	0	28,606	14,303	**292,636**	
28 July 2014	3,69	26,545	15,1175	**307,7535**	250
29 July 2014	0,426	28,794	14,61	**322,3635**	
30 July 2014	0,049	28,294	14,1715	**336,535**	300
31 July 2014	0	32,54	16,27	**352,805**	
01 August 2014	1,305	29,98	15,6425	**368,4475**	
02 August 2014	0,049	28,169	14,109	**382,5565**	
03 August 2014	0	27,544	13,772	**396,3285**	350
04 August 2014	0,74	30,043	15,3915	**411,72**	
05 August 2014	2,749	29,606	16,1775	**427,8975**	
06 August 2014	7,767	29,668	18,7175	**446,615**	
07 August 2014	6,199	26,232	16,2155	**462,8305**	400
08 August 2014	6,513	22,357	14,435	**477,2655**	
09 August 2014	8,018	26,545	17,2815	**494,547**	
10 August 2014	6,952	26,107	16,5295	**511,0765**	450
11 August 2014	4,568	28,794	16,681	**527,7575**	
12 August 2014	3,502	28,856	16,179	**543,9365**	
13 August 2014	2,749	31,729	17,239	**561,1755**	500
14 August 2014	5,886	31,354	18,62	**579,7955**	
15 August 2014	12,217	24,295	18,256	**598,0515**	

16 August 2014	7,83	22,106	14,968	**613,0195**	
17 August 2014	4,129	27,794	15,9615	**628,981**	550
18 August 2014	5,509	31,416	18,4625	**647,4435**	
19 August 2014	6,262	29,481	17,8715	**665,315**	
20 August 2014	7,265	26,67	16,9675	**682,2825**	600
21 August 2014	1,87	24,482	13,176	**695,4585**	
22 August 2014	0	26,42	13,21	**708,6685**	
23 August 2014	1,431	25,92	13,6755	**722,344**	650
24 August 2014	0	30,23	15,115	**737,459**	
25 August 2014	0	31,604	15,802	**753,261**	
26 August 2014	1,117	31,604	16,3605	**769,6215**	
27 August 2014	3,376	30,605	16,9905	**786,612**	700
28 August 2014	2,874	19,855	11,3645	**797,9765**	
29 August 2014	0,238	27,482	13,86	**811,8365**	
30 August 2014	1,995	28,981	15,488	**827,3245**	750
31 August 2014	3,439	31,167	17,303	**844,6275**	
01 September 2014	3,313	30,605	16,959	**861,5865**	
02 September 2014	1,87	33,976	17,923	**879,5095**	
03 September 2014	1,933	33,351	17,642	**897,1515**	800
04 September 2014	2,058	31,604	16,831	**913,9825**	
05 September 2014	2,937	34,974	18,9555	**932,938**	
06 September 2014	4,129	37,781	20,955	**953,893**	850
07 September 2014	6,513	39,713	23,113	**977,006**	
08 September 2014	7,453	35,91	21,6815	**998,6875**	
09 September 2014	5,447	38,778	22,1125	**1020,8**	900
10 September 2014	9,146	37,781	23,4635	**1044,264**	
11 September 2014	6,952	11,089	9,0205	**1053,284**	950
12 September 2014	11,089	36,034	23,5615	**1076,846**	
13 September 2014	9,46	39,776	24,618	**1101,464**	1000

Appendix 6: Summer accumulated-degree days

Date	Minimum Temperature	Maximum Temperature	Average Temperature	Summer ADD	Forecast ADD Interval
06 October 2014	7,505	36,52	22,0125	22,0125	
07 October 2014	8,382	36,458	22,42	44,4325	
08 October 2014	7,191	38,267	22,729	67,1615	50
09 October 2014	9,448	38,89	24,169	91,3305	
10 October 2014	14,271	35,959	25,115	116,4455	100
11 October 2014	13,144	30,841	21,9925	138,438	
12 October 2014	11,453	36,957	24,205	162,643	
13 October 2014	13,833	40,324	27,0785	189,7215	150
14 October 2014	12,267	38,142	25,2045	214,926	
15 October 2014	13,895	31,528	22,7115	237,6375	200
16 October 2014	10,576	33,962	22,269	259,9065	
17 October 2014	8,508	39,077	23,7925	283,699	
18 October 2014	5,937	36,021	20,979	304,678	250
19 October 2014	6,251	39,015	22,633	327,311	
20 October 2014	9,51	41,571	25,5405	352,8515	
21 October 2014	12,831	38,703	25,767	378,6185	300
22 October 2014	10,576	37,83	24,203	402,8215	
23 October 2014	10,638	38,578	24,608	427,4295	350
24 October 2014	12,706	41,072	26,889	454,3185	
25 October 2014	11,641	38,329	24,985	479,3035	
26 October 2014	12,956	22,656	17,806	497,1095	400
27 October 2014	10,638	32,714	21,676	518,7855	
28 October 2014	9,949	36,021	22,985	541,7705	450
29 October 2014	12,017	39,701	25,859	567,6295	
30 October 2014	13,645	43,191	28,418	596,0475	
31 October 2014	16,713	41,883	29,298	625,3455	500
01 November 2014	16,963	34,087	25,525	650,8705	
02 November 2014	14,146	28,468	21,307	672,1775	
03 November 2014	13,708	27,781	20,7445	692,922	550
04 November 2014	14,835	28,405	21,62	714,542	
05 November 2014	11,077	38,953	25,015	739,557	600
06 November 2014	10,764	36,271	23,5175	763,0745	
07 November 2014	13,52	41,633	27,5765	790,651	
08 November 2014	13,269	36,707	24,988	815,639	
09 November 2014	14,334	36,271	25,3025	840,9415	
10 November 2014	15,586	22,714	19,15	860,0915	
11 November 2014	15,398	17,651	16,5245	876,616	700
12 November 2014	14,396	19,529	16,9625	893,5785	
13 November 2014	13,833	33,088	23,4605	917,039	
14 November 2014	12,956	38,953	25,9545	942,9935	800
15 November 2014	9,009	32,901	20,955	963,9485	

16 November 2014	7,317	33,276	20,2965	984,245	
17 November 2014	8,821	25,156	16,9885	1001,234	
18 November 2014	7,818	28,405	18,1115	1019,345	
19 November 2014	7,003	31,778	19,3905	1038,736	
20 November 2014	8,32	33,713	21,0165	1059,752	
21 November 2014	10,074	36,895	23,4845	1083,237	900
22 November 2014	13,708	36,333	25,0205	1108,257	
23 November 2014	13,144	27,718	20,431	1128,688	
24 November 2014	11,954	34,087	23,0205	1151,709	
25 November 2014	12,392	38,204	25,298	1177,007	
26 November 2014	14,083	37,955	26,019	1203,026	1000

Appendix 7: Winter control TBS scores

Forecast ADD Interval	Actual ADD	Head	Torso	Limbs	Total (35)	Standardized TBS (30)
50	60,7155	1	3	1	5	**4,3**
100	119,4755	1	3	1	5	**4,3**
150	169,0895	1	3	1	5	**4,3**
200	221,011	3	3	1	7	**6**
250	307,7535	3	3	1	7	**6**
300	336,535	5	3	1	9	**7,7**
350	396,3285	5	3	1	9	**7,7**
400	462,8305	5	4	1	10	**8,6**
450	511,0765	6	4	3	13	**11,1**
500	561,1755	6	4	3	13	**11,1**
550	628,981	7	4	3	14	**12**
600	682,2825	8	4	3	15	**12,9**
650	722,344	8	5	4	17	**14,6**
700	786,612	8	5	4	17	**14,6**
750	827,3245	8	6	4	18	**15,4**
800	897,1515	8	6	4	18	**15,4**
850	953,893	9	6	4	19	**16,3**
900	1020,8	11	6	4	21	**18**
950	1053,284	11	7	5	23	**19,7**
1000	1101,4635	11	7	5	23	**19,7**

Appendix 8: Winter CGS level 2 TBS scores

ADD		Total Body Scores (Megyesi *et al.* 2005)					Charred Body Scale (Gruenthal *et al*, 2012)					CGS Level 2 TBS				
Forecast ADD Interval	Actual ADD	Head	Torso	Limbs	Total (35)	Standardized TBS (30)	Head	Torso	Limbs	Total (32)	Standardized TBS (30)	Head	Torso	Limbs	Total (29)	Standardized TBS (30)
50	60,7155	1	2	1	4	**3,4**	1	1	2	4	**3,8**	**1**	**1**	**1**	**3**	**3,1**
100	119,4755	1	2	2	5	**4,3**	1	1	3	5	**4,7**	**1**	**1**	**1**	**3**	**3,1**
150	169,0895	5	2	2	9	**7,7**	2	1	3	6	**5,6**	**2**	**1**	**1**	**4**	**4,1**
200	221,011	5	4	4	13	**11,1**	2	2	3	8	**7,5**	**2**	**3**	**2**	**7**	**7,2**
250	307,7535	5	4	4	13	**11,1**	4	4	3	11	**10,3**	**2**	**3**	**2**	**7**	**7,2**
300	336,535	5	4	4	13	**11,1**	4	4	3	11	**10,3**	**2**	**3**	**2**	**7**	**7,2**
350	396,3285	5	4	4	13	**11,1**	5	4	3	12	**11,3**	**2**	**3**	**2**	**7**	**7,2**
400	462,8305	5	4	4	13	**11,1**	5	4	3	12	**11,3**	**2**	**4**	**2**	**8**	**8,3**
450	511,0765	5	4	4	13	**11,1**	5	4	3	12	**11,3**	**2**	**4**	**2**	**8**	**8,3**
500	561,1755	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**2**	**5**	**2**	**9**	**9,3**
550	628,981	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**2**	**5**	**2**	**9**	**9,3**
600	682,2825	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**3**	**5**	**2**	**10**	**10,3**
650	722,344	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**3**	**5**	**2**	**10**	**10,3**
700	786,612	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**4**	**5**	**4**	**14**	**14,5**
750	827,3245	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**4**	**5**	**4**	**14**	**14,5**
800	897,1515	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**4**	**5**	**4**	**14**	**14,5**
850	953,893	5	6	4	15	**12,9**	5	5	3	13	**12,2**	**4**	**5**	**4**	**14**	**14,5**
900	1020,8	7	7	4	18	**15,4**	7	7	3	17	**15,9**	**5**	**6**	**4**	**15**	**15,5**
950	1053,284	7	7	4	18	**15,4**	7	7	3	17	**15,9**	**5**	**6**	**4**	**15**	**15,5**
1000	1101,4635	7	7	4	18	**15,4**	7	7	3	17	**15,9**	**5**	**6**	**4**	**15**	**15,5**

Appendix 9: Summer control TBS scores

Forecast ADD Interval	Actual ADD	Head	Torso	Limbs	Total (35)	Standardized TBS (30)
50	67,1615	5	4	2	11	**9,4**
100	116,4455	6	4	3	13	**11,1**
150	189,7215	7	6	6	19	**16,3**
200	237,6375	7	7	6	20	**17,1**
250	304,678	7	7	6	20	**17,1**
300	378,6185	7	7	6	20	**17,1**
350	427,4295	7	7	7	21	**18**
400	497,1095	8	8	7	23	**19,7**
450	541,7705	8	8	7	23	**19,7**
500	625,3455	8	8	7	23	**19,7**
550	692,922	8	8	7	23	**19,7**
600	739,557	8	8	7	23	**19,7**
700	876,616	8	8	7	23	**19,7**
800	942,9935	9	8	7	24	**20,6**
900	1083,2365	9	8	7	24	**20,6**
1000	1203,0255	9	8	7	24	**20,6**

Appendix 10: Summer CGS level 1 TBS scores

ADD		Total Body Scores (Megyesi *et al.* 2005)					Charred Body Scale (Gruenthal *et al.* 2012)					CGS Level 1 TBS				
Forecast ADD Interval	Actual ADD	Head	Torso	Limbs	Total (35)	Standardized TBS (30)	Head	Torso	Limbs	Total (32)	Standardized TBS (30)	Head	Torso	Limbs	Total (32)	Standardized TBS (30)
50	67,1615	5	2	2	9	**7,7**	1	1	2	4	**3,8**	3	2	1	6	**5,6**
100	116,4455	5	4	2	11	**9,4**	2	3	3	8	**7,5**	4	3	3	10	**9,3**
150	189,7215	8	7	6	21	**18**	7	7	7	21	**19,7**	6	6	5	17	**15,9**
200	237,6375	8	9	8	25	**21,4**	8	7	8	23	**21,6**	7	7	7	21	**19,7**
250	304,678	8	9	8	25	**21,4**	8	8	8	24	**22,5**	7	7	7	21	**19,7**
300	378,6185	8	9	8	25	**21,4**	8	10	8	26	**24,4**	7	7	7	21	**19,7**
350	427,4295	8	9	8	25	**21,4**	8	10	8	26	**24,4**	7	7	7	21	**19,7**
400	497,1095	8	9	8	25	**21,4**	8	10	8	26	**24,4**	7	8	7	22	**20,6**
450	541,7705	8	9	8	25	**21,4**	9	11	8	28	**26,3**	8	8	7	23	**21,6**
500	625,3455	8	9	8	25	**21,4**	9	11	8	28	**26,3**	8	8	7	23	**21,6**
550	692,922	8	9	8	25	**21,4**	9	11	8	28	**26,3**	9	8	7	24	**22,5**
600	739,557	9	9	8	26	**22,3**	9	11	8	28	**26,3**	9	9	7	25	**23,4**
700	876,616	12	9	8	29	**24,9**	10	11	8	29	**27,2**	11	10	7	28	**26,3**
800	942,9935	12	10	8	30	**25,7**	10	11	8	29	**27,2**	11	10	7	28	**26,3**
900	1083,2365	13	11	9	33	**28,3**	11	12	8	31	**29,1**	12	10	8	30	**28,1**
1000	1203,0255	13	11	10	34	**29,1**	11	12	8	31	**29,1**	12	10	9	31	**29,1**

Appendix 11: Summer CGS level 2 TBS scores

ADD		Total Body Scores (Megyesi *et al*. 2005)					Charred Body Scale (Gruenthal *et al.* 2012)					CGS level 2 TBS				
Forecast ADD Interval	Actual ADD	Head	Torso	Limbs	Total (35)	Standardized TBS (30)	Head	Torso	Limbs	Total (32)	Standardized TBS (30)	Head	Torso	Limbs	Total (29)	Standardized TBS (30)
50	67,1615	5	4	1	10	**8,6**	2	2	2	6	**5,6**	2	2	1	5	**5,2**
100	116,4455	5	6	1	12	**10,3**	4	6	3	13	**12,2**	3	5	5	13	**13,4**
150	189,7215	8	7	5	20	**17,1**	8	10	7	25	**23,4**	6	6	5	17	**17,6**
200	237,6375	8	7	6	21	**18**	8	11	7	26	**24,4**	6	6	6	18	**18,6**
250	304,678	8	7	7	22	**18,9**	8	11	7	26	**24,4**	6	6	6	18	**18,6**
300	378,6185	8	7	7	22	**18,9**	8	11	7	26	**24,4**	6	6	6	18	**18,6**
350	427,4295	8	7	7	22	**18,9**	8	11	7	26	**24,4**	6	6	6	18	**18,6**
400	497,1095	9	7	7	23	**19,7**	8	11	7	26	**24,4**	6	7	6	19	**19,7**
450	541,7705	9	7	7	23	**19,7**	8	11	7	26	**24,4**	6	7	6	19	**19,7**
500	625,3455	9	8	7	24	**20,6**	8	11	7	26	**24,4**	6	7	6	19	**19,7**
550	692,922	9	8	7	24	**20,6**	8	11	7	26	**24,4**	6	7	6	19	**19,7**
600	739,557	9	8	7	24	**20,6**	8	11	7	26	**24,4**	7	7	6	20	**20,7**
700	876,616	9	9	7	25	**21,4**	9	11	7	27	**25,3**	7	7	6	20	**20,7**
800	942,9935	10	10	7	27	**23,1**	9	11	7	27	**25,3**	8	7	7	22	**22,8**
900	1083,2365	10	11	7	28	**24**	9	12	8	29	**27,2**	8	8	8	24	**24,8**
1000	1203,0255	10	11	8	29	**24,9**	9	12	8	29	**27,2**	8	8	8	24	**24,8**

Appendix 12: Summer CGS level 3 TBS scores

ADD		Total Body Scores (Megyesi *et al.* 2005)					Charred Body Scale (Gruenthal *et al.* 2012)					CGS Level 3 TBS				
Forecast ADD Interval	Actual ADD	Head	Torso	Limbs	Total (35)	Standardized TBS (30)	Head	Torso	Limbs	Total (32)	Standardized TBS (30)	Head	Torso	Limbs	Total (25)	Standardized TBS (30)
50	67,1615	5	1	1	7	**6**	2	4	2	8	**7,5**	1	1	1	3	**3,6**
100	116,4455	5	4	2	11	**9,4**	2	4	2	8	**7,5**	1	2	1	4	**4,8**
150	189,7215	5	6	2	13	**11,1**	4	5	2	11	**10,3**	2	3	3	8	**9,6**
200	237,6375	5	6	7	18	**15,4**	4	5	7	16	**15**	2	4	5	11	**13,2**
250	304,678	7	8	7	22	**18,9**	7	7	7	21	**19,7**	3	5	5	13	**15,6**
300	378,6185	7	8	7	22	**18,9**	7	7	7	21	**19,7**	3	5	5	13	**15,6**
350	427,4295	7	8	7	22	**18,9**	7	7	7	21	**19,7**	3	5	5	13	**15,6**
400	497,1095	7	8	7	22	**18,9**	7	7	7	21	**19,7**	4	5	5	14	**16,8**
450	541,7705	7	8	7	22	**18,9**	7	7	7	21	**19,7**	4	5	5	14	**16,8**
500	625,3455	9	8	7	24	**20,6**	8	7	7	22	**20,6**	4	5	5	14	**16,8**
550	692,922	9	8	7	24	**20,6**	8	7	7	22	**20,6**	4	5	5	14	**16,8**
600	739,557	9	8	7	24	**20,6**	8	8	7	23	**21,6**	5	5	5	15	**18**
700	876,616	9	8	7	24	**20,6**	8	8	7	23	**21,6**	5	5	5	15	**18**
800	942,9935	9	10	8	27	**23,1**	8	8	7	23	**21,6**	5	6	7	18	**21,6**
900	1083,2365	10	11	9	30	**25,7**	9	9	8	26	**24,4**	6	7	8	21	**25,2**
1000	1203,0255	11	11	9	31	**26,6**	10	10	9	29	**27,2**	7	7	9	23	**27,6**

Appendix 13: Winter control decomposition observations

ADD Interval	Observations			
	Head and Neck	Torso	Limbs	Colonization
0	Pink – no changes	Blue/green abdomen	No changes	None
50	Neck skin is loose	Green discolouration of abdomen persists – extends from abdomen to the back	No changes	None
100	No changes	-Blue/green discolouration persists (no change in extent)	No changes	One fly noticed in mouth
150	No changes	Light green discolouration persists (belly and sides of back)	No changes	Two flies noted on the body
200	-Neck and face exhibiting a green tinge -Brown mark on neck (ant track) -Little body fluid purge out nose pooling on floor	-Greenish tinge persists -Belly skin appears smooth -Skin is shiny	No changes	None
250	No changes	-Slight increase in bloat -Blue/green discolouration persists -Brown ant tracks on left lateral abdomen	Ant tracks spreading over majority of limbs	One fly noted on the body
300	-Extensive body fluid purge from mouth and nose -Ant tracks larger -Holes in cheek skin	-Ant tracks visible on gonads -Brown/green discolouration	Ant tracks have spread	-Multiple flies around head and mouth -Beetles on snout, eyes and mouth -Large maggot in body fluid purge pool
350	-Extensive body fluid purge from mouth and nose -Drying of head skin with hair loss and holes in cheeks -Dry skin flaking and peeling	-Green/brown discolouration -Multiple ant tracks	-Multiple ant tracks -Ants viewed on limbs (between hind thighs)	-Beetles, flies and ants noted on the body
400	-Flesh of the head is actively decomposing -Skin is dry, separating from head, with multiple holes	-Slight bloating -Green discolouration spread over lower abdomen and neck	No changes	-Multiple flies and beetles -No more maggot activity
450	-The neck is exhibiting marbling -Skin slippage and peeling -Ear is red -Blackening of skin around mouth	-Extensive marbling of lower (ground contact) portion -Further bloat	Marbling of upper limbs	Flies and beetles noted on the body
500	-Marked bloat in neck -Multiple perforations in cheeks and neck (below mandible) -Blackening of skin around ears	-Marked bloat -Skin slippage on majority of lower abdomen -Bloat has caused pig to roll onto its back	No changes	-Flies, ants (small & large) and a single beetle noted on the body -small maggot masses beneath abdominal skin slippage -Maggots under limbs (arm pits)
550	-Massive holes in neck & snout -Deflation of neck (skin is taut against jaw) -Green discolouration	-Extreme bloat -Wide spread skin slippage -Marbling of torso	Marbling of lower limbs	-Multiple flies & beetles (of various species and size) noted on the body
600	-Many holes in neck and face -Minimal exposure of bone through skin holes	-Bloat present -Skin slippage of lower abdomen dried	No changes	-Many flies noted on the body -Many beetles (new species present in addition to others) noted on the body -Beetles focused on torso and in/behind ears
650	-Large gaping hole in neck revealing mandibular bone	-Distention -Darker brown discolouration -Dotted with many brown dots	-Dark green discolouration	-Maggot mass in neck and mouth and outside mouth and neck

	-Large maggot mass in neck & outside mouth & neck	- Skin slippage over lower abdomen -Maggot mass clustered under skin		-Multiple beetles on body
700	-Desiccation of skin -Hole in neck is larger -Holes in skin along jaw line at ramus -Full of maggots -Massive tissue fluid purge around head (which is full of maggots)	-Brown discolouration of torso	-Maggot masses beneath left fore- and hind-limbs -Maggot mass under right hip	-Many flies, some beetles, massive maggot masses and many beetle larvae noted on the body
750	-Massive tissue fluid purge (dry) -Maggot masses gone -Pupae present	Onset of abdominal deflation	-Maggot masses under limbs (arm and leg pits) -Beetles present	-Pupae on head -Maggot masses beneath limbs -Beetles on limbs
800	No change	Massive deflation and concavity of abdomen	-Peeling of dry skin -Maggot mass persists beneath fore-limb (in arm pit) -Small, black, round beetles present	- Larvae, ants & flies present on head and neck -New species observed on body: a brown fly and small, round, black beetles
850	-Desiccation of skin -Hair loss	-Extreme deflation of body -Desiccation of abdomen skin	-Large holes beneath limbs in arm pit (no maggots present) -Discolouration to black and grey	Beetles only (few) noted on the body
900	-Skin very dry and cardboard-like in appearance -Peeling / flaking of facial skin -Beetles in face under skin	-Flattened -Dry leathery skin	No changes	-Ants on body -Beetles in head -Flies noted on the body
950	Extremely dry, thin facial skin (newspaper-like appearance)	-Ribs exposed through hole under limb -Skin is black	Skin is black	Few flies, beetle & ants noted on the body
1000	No changes	No changes	No changes	None

Appendix 14: Winter CGS level 2 decomposition observations

ADD Interval	Observations			
	Head and Neck	Torso	Limbs	Colonization
0	- Fresh differential charring of skin -Circular patches in skin (not charred but singed and whitish in appearance) -Uncharred patches of skin are brown	-Fresh differential charring -Circular patches in skin are singed brown -Cracking of skin exposing flesh/muscle beneath -Cracking on the abdomen and back	-Differential charring -Pugilistic pose -Cracking most prominent at limb joints	None
50	No change	-Charred skin cracking/flaking -Skin slippage -Cracks in skin are deeper & longer	-Extreme flaking of charred skin -Open splits in cracked flesh are deeper	None
100	No change	-Skin has a sticky moist appearance of exposed torso -Exposed muscle is dried out	-No major changes -Cracking of thigh skin -Exposed muscle is dried out	None
150	Tissue fluid purge out of nose	Skin has a sticky, moist appearance over the greater area of torso	No change	None
200	Further tissue fluid purge pooling	Slight bloat noted	Severe cracking of hind charred skin	None
250	Flaking of charred skin on snout and jaw	-Flaking of charred skin beginning on torso -Deep split in the back flesh	No change	None
300	No change	Large gaping hole on left back	Further cracking of skin on right limb thigh (revealing white muscle beneath)	None
350	Few maggots in mouth and throat	Back split is larger and infested with maggots	No change	Maggots in back split
400	No more maggot activity in mouth	-Back and sides appear moist with flattened char -Skin cracks further split and spread	No change	-Live and dead maggots in back split -Beetles congregated at face and armpits
450	No change	Wet decomposition in back wound	No change	Fewer maggots in back split
500	Hole in snout leading into oral cavity	-Sagged appearance of abdomen and back (skin has caved in)	No change	None
550	Hole in snout	Further necrosis of back split	No change	Ants below pig
600	Very slight neck bloat observed	Tissue fluid purge exiting back wound	No change	-Beetles in ears & mouth -Two small flies noted on the body
650	No change	-Back split's tissue fluid purge has dried -Very little fluid in back split	No change	
700	Char appears moist and flattened (no longer flaky)	No change	-Skin is cracked on the upper back before the neck -Char is no longer flaky but flattened	-Little maggot activity in wet decomposition in back split -Small fly present on mouth
750	No change	Beetle in back split	No change	Two maggots noted in the mouth
800	No change	-Slightly increased concavity of belly and abdomen between hind limbs -Moist appearance of back skin	No change	None
850	No change	-Large hole formed in left lateral side beneath ribs -Wet decomposition internally -Hollowing in torso	A maggot mass is beneath the left hind limb skin	-Ants, a fly and a beetle noted on the body -Maggots noted in the body cavity in the abdomen
900	-Neck skin has a moist appearance -Neck has caved in	-Internal organs exposed in abdominal hole are dried -Ribs exposed in hole -Further collapse of abdomen -There are many small holes observed above the left thigh	No change	-Tiny flies, tiny beetles and maggots noted in the abdominal hole, back split, thigh holes and mouth

950	-More holes in cheek -Crack in back neck skin	-Belly has collapsed more -Lower back skin cracks are separating the skin and flesh	Skin is cracked and separating at the hip joints and shoulder joints	-Few flies, ants, beetles around body -A new species of fly noted on the body (long, black, small flies)
1000	No change	No change	No change	None

Appendix 15: Summer control decomposition observations

ADD Interval	Observations			
	Head and Neck	Torso	Limbs	Colonization
50	-Bloated neck -Hypostasis of neck -Protruding tongue	-Bloated (rolled onto back) -Hypostasis -Onset of marbling -3x large skin blisters (fluid filled) on right abdomen	-Extended due to bloat -Hypostasis of right limbs	Massive swarm of flies – focused at mouth, eyes and behind ears -Many ants on hind limbs
100	Blackening of skin particularly the neck	-Blackened hypostasis -Skin slippage on the right side, abdomen & rump -Herniation at the abdomen -Exposed intestines	-Blackened hypostasis -Extended outwards	-Maggots in mouth -Maggot masses at the intestine opening, anus and right side (ground contact) and at the leg joints -Large fly swarm
150	-Wet decomposition -Skin slippage -Tongue gone -Black & brown skin discolouration -Hair loss in mats	-Deflated -Black, brown, white discolouration -Chest still has integrity	-Skin slippage -Hair loss in mats -Bones exposed in front lower right limb	-Massive maggot masses at abdomen, back, mouth, eyes, ears, limbs -Flies
200	-Blackening of skin -Hair loss -Skin slippage -Mouth & eyes eaten by maggots -neck deflated	-Completely deflated -Skin slippage -Black discolouration	-Black discolouration -Skin slippage -Holes exposing skeletal elements -Hair loss	-Maggot masses in mouth, ears, abdomen, limbs, eyes -Few flies & 2x blue metallic beetles
250	-Wet skin -Skin slippage on ears -Large oval holes in ears & beneath chin	-Large oval holes in belly -Flattened	-Large oval holes in lower limbs	None
300	Moist neck	NA	Many holes over all limbs	None
350	-Small holes around rim of mouth -Skin slippage & hair loss	NA	-More holes in limbs -Bones exposed in hind upper limbs	Small fly swarm
400	NA	Leathery skin	NA	Beetles present
450	NA		Bones visible at all limbs (except front left) through holes in skin	-Few flies -Metallic blue beetles
500	Mandible bone exposed through skin hole	NA	-Bones (phalanges) exposed on right fore-limb and femur of right hind limb & left tibia & fibula	None
550	NA	Multiple small holes	Multiple small holes over all limbs exposing bone beneath	Many varieties of beetles & flies
600	-Moist skin -Skin taught against jaw	-Drying -Many holes & moth-eaten appearance holes on exposed underside	-Moist skin & internal decomposed tissue -Many holes in skin exposing bone	Few small flies
700	Multiple holes in jaw and neck skin	Increased number of moth-eaten appearance holes	-More holes -Moist decomposition -Hooves loose and separated exposing underlying phalangeal bones	Beetle larvae
800	-Dried/desiccated skin -Maxillary and mandibular bone exposure through skin holes -Large hole behind eye	Further desiccation and increase in number of moth-eaten appearance holes	Skin desiccation	None
900	-Skin peeling back over maxilla and mandible exposing more bone - Hole behind eye expanded and including orbit	Holes are much larger	-Skin is black -Front limbs mostly skeletonized, hind limbs still covered in skin	None
1000	Further desiccation of skin (dry, leathery, hard) and expansion of holes	-Ribs exposed through large moth-eaten appearance holes	Bone exposure increased	None

Appendix 16: Summer CGS level 1 decomposition observations

ADD Interval	Observations			
	Head and Neck	Torso	Limbs	Colonization
50	-Protruding tongue -Split skin on neck	-Open wound on back > actively leaking tissue fluid	Skin split on limbs > revealing white/pink flesh beneath	Massive swarm of flies focused at mouth, open wounds & eyes
100	-Tongue protruding & bloated -Tissue fluid purge from mouth & nose -Moist skin (tissue fluid) -Eyes putrefied	-Herniation & intestine exposure -Blister forming on left lateral rump -Anal bloat -Large back hump bloat causing splitting skin down the middle (cranial-caudal axis)	Blisters between hind limbs & forelimbs	-Fly swarm (medium) -Small maggot mass in exposed ear
150	-Neck skin gone -Cheek skin gone -Eyes gone -Mandible & jaw bone exposed	-Deflated -Two ribs exposed -Back hump gone -Skin separated from flesh -Blister marks remain	-Humeri, radii, ulnae femora, tibia and fibulae skeletonized with some skin remaining -Blister marks remain	-Massive maggot masses at neck, mouth, eyes, neck, back, torso, rump, limbs -No flies
200	-Bone & leather-like skin remains -Destruction of cheeks, eyes, mouth, neck & throat	-Completely deflated -Ribs exposed -Leathery skin -Organs putrefied and muscle tissue putrefying	No change	-Few flies -Maggot mass at abdomen
250	No change	Ribcage exposed at sternal and vertebral ends	Lower limbs retain char and blister marks	None
300	No change	No change	No change	None
350	-Cheek skin gone -Skin beneath jaw has a large hole -Hind neck skin has very large holes	-Rib cage exposed further at the back and sides -Many small holes in lateral torso	No change	Small fly swarm
400	-Skin separated from skull -Maxilla & mandible exposed	Ribs & vertebral column exposed	No change	Few flies & beetles
450	Cervical vertebrae exposed	Rib cage exposed	No change	Metallic blue beetles
500	Only leathery skin covering head	Rib cage & vertebral column exposed	No change	None
550	Skin separating from skull in large sheets	Ribs & vertebrae exposed	No change	Various beetles & larvae
600	-Skeletonized & dry skin -Greasy bone	-Ribs & spine greasy -Some skin & moist internal decomposed tissue	Greasy bone & dry skin on lower limbs	None
700	Completely skeletonized - greasy	Completely skeletonized (greasy) with minor decomposed tissue strands	No change	None
800	Still greasy	Greasy bone	Lower limbs (phalanges) covered by desiccated skin	None
900	Dry	Greasy bone	Skeletonized	None
1000	Dry	Greasy bone	Drying	None

Appendix 17: Summer CGS level 2 decomposition observations

ADD Interval	Observations			
	Head and Neck	Torso	Limbs	Colonization
50	-Skin split on neck -large open wounds on snout & neck -Tissue fluid seeping from nose and hole in cheek -Snout disk shot out	-Skin split -Large open wounds on back -Intestinal herniation at abdomen	-Skin cracked -Pugilistic pose -Muscle exposed	-Ants on limbs -Large fly swarm focused at mouth, back wound & intestines
100	-Open wounds in cheek & neck -Moist skin -Skin cracked largely on neck -Slight bloat	-Caved in -Large laceration appearance wounds -Large wounds on back	-Large lacerating wounds -Char is moist	-Maggot masses in mouth & intestines -Few flies
150	-Neck skin gone -Skeletonization of neck and ramus -Leathery skin	-Skeletonization & active decay -Ribs & vertebral column exposed -Ribs displaced -Leathery skin	No Change	-Maggot mass at mouth, neck, torso, legs, "intestine"
200	More neck destruction	No Change	Right hind femur skeletonized	-Few scattered maggots -Many metallic blue beetles
250	No Change	Ribs starting to be sun bleached	No Change	None
300	No Change	No Change	Still whole	None
350	Skin around mouth gone & beneath jaw is a large hole	Large hole in left lateral rump	No Change	Small fly swarm
400	-Neck wide open -Fleshy with bone exposure	Skin, bone & decomposition	Fleshed, >50% skeleton exposed	Few beetles & flies
450	Ramus bleached	No Change	-Right femur, tibia and fibula skeletonized -Hind left femur exposed	Many metallic blue beetles
500	No Change	Scapula exposed	No Change	None
550	Skin separating from skull in large sheets	No Change	No Change	Various beetles & flies
600	-Dry bone covered with dry mask-like skin -Neck still fleshy & decomposing	-Ribs & vertebrae dry & disarticulating -Skin moist with wet decomposed tissue	-Greasy bone & skin (dry) on lower limbs -Upper limbs still have thick skin even though femora are exposed	Small flies
700	-Flesh is now moist decomposition due to rain – minimal char remains (turned brown)	Rain turned flesh moist and white	No Change	Beetle larvae on head, forelimbs and torso
800	-Head mostly skeletonized with upper face covered by leathery skin -Neck has fleshy strands	Mostly skeletonised (greasy) with minimal flesh remaining at rump and shoulders	Humeri, ulnae and radii of fore-limbs skeletonized (greasy)	None
900	-Head greasy bone and minimal skin -Neck vertebrae exposed with stringy flesh	Greasy bone	No Change	None
1000	Mostly greasy bone with some skin and flesh	Dry bone	No Change	None

Appendix 18: Summer CGS level 3 decomposition observations

ADD Interval	Observations			
	Head and Neck	Torso	Limbs	Colonization
50	-Pink tissue fluid leakage from nose	-Large wound on back -Tail skin separated from tail	-Skin cracked -Tissue, muscle & bone exposed -Pugilistic pose -Severely charred, limbs are all severed at joints (knees) – near amputation	-No fly or ant activity
100	No Change	Fluid purge from anus	No Change	-Medium fly swarm
150	Skin peeling/flaking	-Skin flaking/peeling -Moist -Muscles & strands exposed -Pooling of blood in back wound -Slight collapse of abdomen	-Moist -Skin slippage	-Fly swarm -Few maggots in mouth
200	No Change	-Deflated -Hole in abdomen -Major destruction of hind rump (exposure of muscle)	Right radius exposure	-Few flies -Maggot mass at belly, abdomen, back, rump
250	-Neck caved in & large holes present in neck and throat -Neck wet	-Spinal column exposed -Wet appearance	No change	Maggot mass in torso
300	Massive holes in neck & throat	-Pelvic bone (ilium) starting to be exposed -Hole in torso exposing a rib	No Change	None
350	No Change	Multiple holes along lateral side between ribs	-Front limbs (very charred and no change) -Right fibula exposed	Small fly swarm
400	-Massive throat cavity -Fleshy -Mouth purge	-Rib cage decomposing exposing a rib -Fleshy	No Change	Few beetles & flies
450	No Change	4x ribs exposed through holes in skin	Large hole above left front limb	Metallic blue beetles
500	Large holes in neck & throat	-Large hole in chest -Thoracic to lumbar vertebrae exposed	No Change	None
550	No Change	No Change	No Change	Various beetles & tiny flies
600	-Greasy bone covered with leathery skin (almost fully covered in skin) -Large gaping hole in neck	-Moist skin decomposing -Ribs exposed -Vertebrae & pelvis bone greasy with decomposed tissue	-Greasy bone exposure but covered in dry skin & flesh -Left humerus exposed	Few beetles
700	Char missing, biomass decrease and mandible ramus visible	-Greater exposure of vertebrae and ribs -Char is lesser and more light brown	Exposed bones become more exposed	None
800	Most of mandible bone exposed	Vertebral column and ribs mostly exposed with charred skin still adhering	-Humeri, radii and ulnae of fore limbs exposed -Femora, tibiae and fibulae exposed	None
900	Most of skull bone exposed with some leathery, charred skin still attached	Skeletonized with minimal tissue	Fore limbs skeletonized completely & hind limbs mostly skeletonized except for lower limbs (phalanges)	None
1000	Skeletonized (greasy) with minimal charred skin	No Change	Completely skeletonized & mostly dry	None

Appendix 19: Standardised body region scores

ADD	Summer control pig			Summer CGS level 1 pig			Summer CGS level 2 pig			Summer CGS level 3 pig		
	Head region standardised score (10)	Torso region standardised score (10)	Limbs standardised score (10)	Head region standardised score (10)	Torso region standardised score (10)	Limbs standardised score (10)	Head region standardised score (10)	Torso region standardised score (10)	Limbs standardised score (10)	Head region standardised score (10)	Torso region standardised score (10)	Limbs standardised score (10)
67,1615	3,85	3,33	2	2,5	1,82	1,11	2	2,22	1	1,25	1,25	1,11
116,4455	4,62	3,33	3	3,33	2,73	3,33	3	5,56	5	1,25	2,5	1,11
189,7215	5,38	5	6	5	5,45	5,56	6	6,67	5	2,5	3,75	3,33
237,6375	5,38	5,83	6	5,83	6,36	7,78	6	6,67	6	2,5	5	5,56
304,678	5,38	5,83	6	5,83	6,36	7,78	6	6,67	6	3,75	6,25	5,56
378,6185	5,38	5,83	6	5,83	6,36	7,78	6	6,67	6	3,75	6,25	5,56
427,4295	5,38	5,83	7	5,83	6,36	7,78	6	6,67	6	3,75	6,25	5,56
497,1095	6,15	6,67	7	5,83	7,27	7,78	6	7,78	6	5	6,25	5,56
541,7705	6,15	6,67	7	6,67	7,27	7,78	6	7,78	6	5	6,25	5,56
625,3455	6,15	6,67	7	6,67	7,27	7,78	6	7,78	6	5	6,25	5,56
692,922	6,15	6,67	7	7,5	7,27	7,78	6	7,78	6	5	6,25	5,56
739,557	6,15	6,67	7	7,5	8,18	7,78	7	7,78	6	6,25	6,25	5,56
876,616	6,15	6,67	7	9,17	9,09	7,78	7	7,78	6	6,25	6,25	5,56
942,9935	6,92	6,67	7	9,17	9,09	7,78	8	7,78	7	6,25	7,5	7,78
1083,237	6,92	6,67	7	10	9,09	8,89	8	8,89	8	7,5	8,75	8,89
1203,026	6,92	6,67	7	10	9,09	10	8	8,89	8	8,75	8,75	10

Appendix 20: Charred Body Scale Interobserver scores

CBS Head Scores									
Pig	**Observer 1**	**Observer 2**	**Observer 3**	**Observer 4**	**Observer 5**	**Observer 6**	**Observer 7**	**Observer 8**	**Observer 9**
1	1	4	1	4	1	1	4	5	2
2	7	7	7	7	4	8	7	7	7
4	4	4	2	4	4	6	4	4	5
5	1	6	6	6	1	6	4	1	7
7	2	4	4	4	3	7	4	4	6
8	8	8	8	7	7	9	8	8	8
9	2	7	6	7	1	5	4	1	6
10	2	7	7	7	1	6	6	1	6
11	2	2	2	4	4	3	2	2	4
12	9	8	8	7	8	8	8	8	8
13	9	10	9	10	8	10	10	9	10
15	1	2	1	4	1	3	1	1	4
16	7	7	6	7	3	6	7	1	7
17	11	11	11	11	12	11	11	10	11
18	8	9	8	8	7	8	9	8	8
19	9	10	9	8	7	9	10	9	9
21	8	8	8	8	7	8	9	8	8
23	8	8	7	7	9	8	7	8	8
24	9	8	7	7	8	8	8	8	8
25	4	5	7	6	3	6	5	1	7
26	2	2	4	2	2	4	4	2	4
27	8	8	8	8	7	8	8	8	8
28	8	8	8	8	8	8	8	8	8
31	8	8	6	7	7	8	8	8	8
32	8	8	8	8	7	8	8	8	8
35	8	7	7	7	4	7	7	1	7
36	8	8	7	7	7	8	8	8	8
37	9	10	10	10	9	9	10	10	9
38	8	7	7	7	4	7	7	7	7
40	8	8	8	8	7	8	8	8	8
41	7	6	7	7	4	6	6	7	7
42	11	10	11	10	12	11	11	11	11
43	9	8	6	7	8	8	8	8	8
44	10	10	10	10	7	10	10	10	10
45	9	8	8	8	9	8	8	8	8
46	8	8	7	7	7	8	8	8	8
48	8	7	7	7	5	8	7	7	8
49	7	7	7	7	4	7	7	7	8
50	8	8	8	8	7	8	8	8	7
53	8	8	8	8	6	8	8	8	8
54	8	7	8	7	5	8	8	8	7
55	8	8	8	8	7	8	8	8	8
57	10	11	11	10	11	10	11	11	10

58	8	8	8	8	8	8	8	8	8
60	7	7	3	7	6	8	7	5	8
63	10	10	10	10	11	10	10	10	10
64	8	8	8	8	6	8	8	8	8
65	9	8	8	8	8	9	8	9	8
66	9	9	8	9	8	10	8	8	8
68	4	6	6	7	2	6	5	1	7
71	7	7	6	7	4	6	7	1	7

CBS Torso Scores									
Pig	**Observer 1**	**Observer 2**	**Observer 3**	**Observer 4**	**Observer 5**	**Observer 6**	**Observer 7**	**Observer 8**	**Observer 9**
1	1	4	2	3	3	4	4	4	2
2	7	7	7	9	4	7	8	8	7
4	6	7	6	6	5	7	7	6	7
5	4	5	4	5	1	7	4	4	4
7	2	6	3	6	3	7	4	6	6
8	10	10	11	7	8	7	8	8	8
9	4	4	4	4	1	5	4	4	4
10	4	4	4	5	1	4	6	2	4
11	3	6	2	6	4	6	6	6	6
12	11	11	11	9	8	9	8	8	8
13	12	11	11	11	7	11	12	12	12
15	1	2	1	3	3	4	2	4	6
16	7	7	7	9	4	7	7	7	7
17	12	12	11	11	11	11	11	11	11
18	11	11	11	8	7	9	9	8	8
19	9	11	12	11	7	11	11	11	11
21	11	11	10	8	7	9	10	8	9
23	7	8	8	7	7	7	8	9	9
24	11	10	11	9	8	7	8	10	9
25	5	7	6	5	3	7	4	4	6
26	2	6	6	6	3	6	6	6	6
27	11	10	11	8	7	9	9	11	9
28	11	10	9	8	7	10	10	11	10
31	8	7	7	7	7	7	7	8	7
32	11	10	11	8	7	9	10	11	9
35	7	10	7	8	4	7	7	8	7
36	10	10	7	8	7	7	7	8	7
37	12	11	12	11	8	11	11	11	11
38	7	10	7	9	5	7	7	8	7
40	11	9	11	8	7	9	9	11	9
41	7	7	7	7	5	7	7	11	7
42	12	12	11	11	11	11	11	12	10
43	11	10	8	7	8	9	7	11	7
44	10	12	11	11	7	11	11	12	10
45	11	11	11	11	9	9	8	11	10
46	10	8	7	7	7	7	7	8	7

48	8	10	7	9	5	7	7	8	7
49	7	7	7	9	5	7	7	7	7
50	11	9	11	8	7	9	10	7	7
53	8	10	11	10	6	10	11	11	8
54	8	10	9	9	5	7	8	11	7
55	11	11	11	8	7	9	9	11	8
57	11	11	11	11	10	11	11	12	10
58	11	9	10	11	7	9	9	11	9
60	7	7	3	7	5	7	7	9	7
63	11	11	11	11	9	11	11	11	11
64	10	10	7	10	6	9	9	8	9
65	11	10	10	11	6	9	10	11	9
66	11	11	11	11	7	10	11	11	9
68	5	5	4	4	2	6	4	4	6
71	7	7	7	9	5	7	7	8	7

CBS Limbs Scores									
Pig	**Observer 1**	**Observer 2**	**Observer 3**	**Observer 4**	**Observer 5**	**Observer 6**	**Observer 7**	**Observer 8**	**Observer 9**
1	2	3	1	2	2	3	3	3	3
2	7	7	6	2	4	7	7	7	7
4	3	3	4	1	5	7	1	4	3
5	3	3	3	3	3	7	7	3	7
7	2	4	2	6	2	7	1	3	3
8	8	7	7	7	4	7	7	7	8
9	2	3	3	3	1	3	2	3	6
10	2	6	3	4	4	7	3	3	6
11	3	3	3	2	2	3	2	3	3
12	8	7	6	7	3	7	7	7	8
13	8	8	6	7	8	7	8	8	7
15	2	2	2	3	4	3	2	3	3
16	7	7	4	6	4	7	6	3	7
17	8	9	8	8	9	8	9	8	8
18	7	7	6	4	5	7	7	6	8
19	8	8	8	8	9	8	9	8	7
21	7	7	5	3	5	7	6	6	7
23	8	7	6	7	5	7	6	7	8
24	8	7	7	7	6	7	7	8	7
25	7	4	4	3	2	7	6	3	3
26	1	3	3	3	2	5	3	2	7
27	7	7	5	3	6	7	7	7	7
28	7	7	6	2	6	7	7	7	7
31	8	7	7	7	5	7	7	7	7
32	7	7	4	3	6	7	6	7	7
35	7	7	7	6	5	7	6	6	8
36	8	7	6	7	5	7	7	7	7
37	8	8	7	7	9	8	8	8	6
38	7	6	6	5	5	7	7	6	7

40	7	6	5	3	6	7	5	7	6
41	7	7	7	7	5	7	7	2	7
42	8	8	9	8	9	8	8	9	8
43	8	7	7	7	6	7	7	7	7
44	9	8	8	8	8	8	8	9	8
45	8	7	7	7	6	7	7	8	7
46	8	7	7	7	6	7	7	7	7
48	7	7	7	6	6	7	7	6	7
49	7	7	7	5	5	7	7	6	7
50	7	7	6	3	6	7	6	6	7
53	7	8	7	8	7	7	8	7	7
54	7	7	7	7	5	7	7	7	7
55	7	7	7	5	6	7	7	7	7
57	8	8	8	8	8	8	8	9	8
58	7	7	6	6	8	7	7	7	7
60	7	7	2	7	5	7	6	7	7
63	8	8	8	7	7	8	7	8	8
64	7	6	5	3	5	6	6	4	7
65	7	7	7	7	8	7	7	7	7
66	7	7	7	7	8	7	7	7	7
68	2	6	4	6	4	7	7	3	7
71	7	7	6	6	5	7	7	6	7

CBS Total Scores									
Pig	**Observer 1**	**Observer 2**	**Observer 3**	**Observer 4**	**Observer 5**	**Observer 6**	**Observer 7**	**Observer 8**	**Observer 9**
1	4	11	4	9	6	8	11	12	7
2	21	21	20	18	12	22	22	22	21
4	13	14	12	11	14	20	12	14	15
5	8	14	13	14	5	20	15	8	18
7	6	14	9	16	8	21	9	13	15
8	26	25	26	21	19	23	23	23	24
9	8	14	13	14	3	13	10	8	16
10	8	17	14	16	6	17	15	6	16
11	8	11	7	12	10	12	10	11	13
12	28	26	25	23	19	24	23	23	24
13	29	29	26	28	23	28	30	29	29
15	4	6	4	10	8	10	5	8	13
16	21	21	17	22	11	20	20	11	21
17	31	32	30	30	32	30	31	29	30
18	26	27	25	20	19	24	25	22	24
19	26	29	29	27	23	28	30	28	27
21	26	26	23	19	19	24	25	22	24
23	23	23	21	21	21	22	21	24	25
24	28	25	25	23	22	22	23	26	24
25	16	16	17	14	8	20	15	8	16
26	5	11	13	11	7	15	13	10	17
27	26	25	24	19	20	24	24	26	24

28	26	25	23	18	21	25	25	26	25
31	24	22	20	21	19	22	22	23	22
32	26	25	23	19	20	24	24	26	24
35	22	24	21	21	13	21	20	15	22
36	26	25	20	22	19	22	22	23	22
37	29	29	29	28	26	28	29	29	26
38	22	23	20	21	14	21	21	21	21
40	26	23	24	19	20	24	22	26	23
41	21	20	21	21	14	20	20	20	21
42	31	30	31	29	32	30	30	32	29
43	28	25	21	21	22	24	22	26	22
44	29	30	29	29	22	29	29	31	28
45	28	26	26	26	24	24	23	27	25
46	26	23	21	21	20	22	22	23	22
48	23	24	21	22	16	22	21	21	22
49	21	21	21	21	14	21	21	20	22
50	26	24	25	19	20	24	24	21	21
53	23	26	26	26	19	25	27	26	23
54	23	24	24	23	15	22	23	26	21
55	26	26	26	21	20	24	24	26	23
57	29	30	30	29	29	29	30	32	28
58	26	24	24	25	23	24	24	26	24
60	21	21	8	21	16	22	20	21	22
63	29	29	29	28	27	29	28	29	29
64	25	24	20	21	17	23	23	20	24
65	27	25	25	26	22	25	25	27	24
66	27	27	26	27	23	27	26	26	24
68	11	17	14	17	8	19	16	8	20

Appendix 21: CGS 1 TBS Interobserver scores

CGS TBS 1 Head Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
1	3	2	3	3	3	1	1	3
8	7	7	6	6	8	6	7	7
11	4	4	4	3	4	3	2	4
12	8	8	7	6	8	6	6	7
15	1	1	1	3	2	1	1	1
17	12	11	12	11	12	12	11	11
23	7	6	6	5	6	6	7	6
24	9	8	7	6	6	6	7	7
31	7	6	6	5	7	6	7	7
36	7	6	6	5	7	6	7	7
42	12	12	12	11	12	12	11	11
43	8	8	7	6	7	6	7	7
45	9	9	8	6	9	7	7	8
46	7	7	7	6	7	7	7	6
57	11	12	11	11	11	11	11	11
60	6	5	6	5	6	6	6	6
63	11	11	11	11	10	12	11	11

CGS TBS 1 Torso Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
1	2	2	3	2	2	2	2	3
8	8	7	8	7	7	6	6	7
11	3	5	4	3	4	3	2	4
12	8	8	8	7	8	6	6	7
15	1	1	1	4	2	1	2	3
17	10	10	10	9	9	10	10	9
23	7	7	7	7	6	6	6	6
24	8	8	8	8	7	6	8	7
31	7	8	7	7	8	6	8	7
36	7	8	7	7	7	6	8	7
42	10	10	10	9	9	10	10	9
43	8	8	8	8	8	7	8	7
45	9	9	9	9	8	8	8	9
46	7	8	6	7	7	6	8	7
57	10	10	9	9	9	10	10	9
60	6	5	5	6	6	5	5	5
63	10	10	9	9	9	9	9	10

CGS TBS 1 Limbs Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
1	1	2	2	1	4	2	2	3
8	7	7	5	7	6	5	7	5
11	3	2	3	1	4	4	2	4
12	7	7	5	7	7	5	7	5
15	1	2	1	1	4	2	2	4
17	8	9	8	8	8	9	9	8
23	7	7	5	7	6	6	7	5
24	7	7	6	7	5	5	7	5
31	7	7	5	7	6	5	7	5
36	7	7	5	7	5	5	7	5
42	9	9	8	9	9	9	9	10
43	7	7	5	7	7	7	7	7
45	7	7	6	7	7	7	7	7
46	7	7	5	7	6	6	7	7
57	7	8	7	8	8	8	9	8
60	5	5	4	6	5	5	5	5
63	7	7	7	7	7	8	7	7

CGS TBS 1 Total Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
1	6	6	8	6	9	5	5	9
8	22	21	19	20	21	17	20	19
11	10	11	11	7	12	10	6	12
12	23	23	20	20	23	17	19	19
15	3	4	3	8	8	4	5	8
17	30	30	30	28	29	31	30	28
23	21	20	18	19	18	18	20	17
24	24	23	21	21	18	17	22	19
31	21	21	18	19	21	17	22	19
36	21	21	18	19	19	17	22	19
42	31	31	30	29	30	31	30	30
43	23	23	20	21	22	20	22	21
45	25	25	23	22	24	22	22	24
46	21	22	18	20	20	19	22	20
57	28	30	27	28	28	29	30	28
60	17	15	15	17	17	16	16	16
63	28	28	27	27	26	29	27	28

Appendix 22: CGS 2 TBS Interobserver scores

CGS TBS 2 Head Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
4	3	2	4	4	3	2	1	2
7	2	3	3	4	5	3	1	2
13	8	8	8	6	8	8	8	8
18	6	7	7	6	7	6	7	6
21	6	6	6	6	6	6	5	6
26	1	3	3	2	3	2	1	2
27	6	7	7	6	7	6	5	6
28	6	6	6	6	6	6	5	6
32	6	6	7	6	7	6	5	6
37	8	8	9	8	8	9	8	8
40	6	7	7	6	7	6	5	6
50	6	6	7	6	7	6	5	6
55	6	7	7	6	7	6	5	6
58	7	7	7	6	6	6	5	7
64	6	6	6	6	6	6	5	6
65	7	6	8	6	7	7	7	7
66	8	8	8	6	8	8	6	8

CGS TBS 2 Torso Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
4	5	3	3	3	5	3	3	5
7	2	3	3	3	4	3	3	5
13	8	8	8	7	8	7	7	7
18	7	6	6	6	6	6	6	7
21	6	6	6	6	6	6	6	7
26	2	2	2	3	3	2	3	2
27	7	6	6	6	7	6	6	7
28	6	6	6	6	6	6	6	7
32	6	6	6	6	6	6	6	7
37	8	8	8	7	8	8	7	8
40	7	7	6	6	7	7	6	7
50	6	6	6	6	6	6	6	7
55	7	7	6	7	7	6	6	7
58	7	6	6	7	6	7	6	7
64	6	6	6	6	6	7	6	7
65	7	6	7	7	7	7	6	7
66	7	7	7	7	7	8	8	8

CGS TBS 2 Limbs Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
4	5	1	3	1	3	2	2	2
7	1	2	3	1	2	2	2	2
13	8	8	8	8	7	9	8	8
18	6	6	6	6	6	6	5	6
21	6	5	6	6	6	6	5	6
26	2	1	3	1	2	2	1	2
27	6	6	6	5	6	6	5	6
28	6	6	6	5	6	6	5	6
32	6	6	6	5	6	6	5	6
37	8	9	8	8	7	9	8	8
40	6	6	6	5	6	6	5	6
50	6	6	6	5	6	6	5	6
55	6	6	6	5	6	6	5	6
58	6	6	6	5	6	6	5	6
64	5	5	5	5	5	5	5	6
65	6	7	7	8	6	8	5	6
66	7	8	8	8	6	8	8	7

CGS TBS 2 Total Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
4	13	6	10	8	11	7	6	9
7	5	8	9	8	11	8	6	9
13	24	24	24	21	23	24	23	23
18	19	19	19	18	19	18	18	19
21	18	17	18	18	18	18	16	19
26	5	6	8	6	8	6	5	6
27	19	19	19	17	20	18	16	19
28	18	18	18	17	18	18	16	19
32	18	18	19	17	19	18	16	19
37	24	25	25	23	23	26	23	24
40	19	20	19	17	20	19	16	19
50	18	18	19	17	19	18	16	19
55	19	20	19	18	20	18	16	19
58	20	19	19	18	18	19	16	20
64	17	17	17	17	17	18	16	19
65	20	19	22	21	20	22	18	20
66	22	23	23	21	21	24	22	23

Appendix 23: CGS 3 TBS Interobserver scores

CGS TBS 3 Head Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
2	4	4	1	4	4	5	1	2
5	1	2	3	2	1	2	1	1
9	1	1	3	2	2	1	1	1
10	1	3	2	2	3	1	1	1
16	3	4	4	1	3	3	4	3
19	6	5	6	5	6	6	5	6
25	2	3	3	2	3	2	1	2
35	4	4	4	4	4	3	1	4
38	4	4	4	4	4	4	1	4
41	3	4	4	3	4	4	1	4
44	7	7	6	6	7	6	6	6
48	5	4	5	4	5	4	4	4
49	4	4	4	4	4	4	4	4
53	5	5	5	5	5	5	5	5
54	5	4	5	4	5	5	4	4
68	2	3	3	2	1	1	1	2
71	3	4	4	2	2	3	1	2

CGS TBS 3 Torso Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
2	5	5	2	5	5	5	4	4
5	1	1	2	2	2	2	1	1
9	2	1	2	2	3	1	1	1
10	1	3	2	2	4	1	1	2
16	5	5	4	5	5	5	4	5
19	7	7	6	7	6	7	6	6
25	4	3	3	1	4	1	1	3
35	5	5	4	5	5	5	5	5
38	5	5	4	5	5	5	5	5
41	5	5	3	4	5	5	5	5
44	7	7	7	7	7	7	7	7
48	5	5	5	5	5	5	4	5
49	5	5	4	5	5	5	4	5
53	6	6	6	6	5	6	6	6
54	5	5	5	5	5	5	5	5
68	3	3	2	1	4	1	1	3
71	5	5	4	4	5	4	1	5

CGS TBS 3 Limbs Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
2	5	5	1	5	5	6	4	5
5	1	1	2	2	5	3	1	5
9	1	1	4	2	5	1	1	5
10	1	3	3	2	5	1	1	5
16	5	5	4	5	5	5	4	5
19	8	8	7	7	8	8	9	8
25	5	2	4	4	5	1	1	5
35	5	5	5	5	5	5	4	5
38	5	5	5	5	5	6	4	5
41	5	5	5	4	5	5	4	5
44	9	8	8	8	8	9	9	9
48	5	5	5	6	5	7	4	5
49	5	5	5	5	5	6	4	5
53	7	7	6	8	6	7	8	7
54	5	6	5	6	5	6	5	5
68	3	4	4	1	5	1	1	5
71	5	5	5	5	5	5	1	5

CGS TBS 3 Total Scores								
Pig	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	Observer 6	Observer 7	Observer 8
2	14	14	4	14	14	16	9	11
5	3	4	7	6	8	7	3	7
9	4	3	9	6	10	3	3	7
10	3	9	7	6	12	3	3	8
16	13	14	12	11	13	13	12	13
19	21	20	19	19	20	21	20	20
25	11	8	10	7	12	4	3	10
35	14	14	13	14	14	13	10	14
38	14	14	13	14	14	15	10	14
41	13	14	12	11	14	14	10	14
44	23	22	21	21	22	22	22	22
48	15	14	15	15	15	16	12	14
49	14	14	13	14	14	15	12	14
53	18	18	17	19	16	18	19	18
54	15	15	15	15	15	16	14	14
68	8	10	9	4	10	3	3	10
71	13	14	13	11	12	12	3	12

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