Estimating the Post-mortem Interval using Accumulated Degree-Days in a South African Setting

by

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DECLARATION

I, Jolandie Myburgh, declare that this thesis is my own work. It is being submitted for the degree of Masters of Science in Anatomy at the University of Pretoria. It has not been submitted before for any other degree or examination at this or any other University.

Sign____________________

This_______ day of ________________, 2010

ABSTRACT

Providing a presumptive identification of badly decomposed or skeletonized remains is the responsibility of a forensic anthropologist. An important component of identification is the estimation of a post-mortem interval (PMI) for the deceased. This information can: provide a window period for death, reduce the number of potential victims, exclude possible assailants and substantiate witness testimony. Due to a large number of open and relatively desolate fields in South Africa, human remains are frequently discovered in an advanced stage of decomposition. The aim of this study was to evaluate the usability of the method of Megyesi and associates (2005) in which Total Body Score (TBS) and Accumulated Degree-Days (ADD) were retrospectively applied to estimate the post-mortem interval (PMI). To achieve this, a longitudinal examination of quantitative variables, TBS and ADD, was conducted over a period of 8 months. This period included both summer and winter seasons. Scatter plots between TBS and PMI, and TBS and ADD were used to illustrate patterns in decomposition. Patterns of decay differed in winter and summer, with winter exhibiting distinct inactivity. Using Loglinear Random-effects Maximum Likelihood Regression, the r^2 values for ADD (0.6227) and PMI (0.5503) for combined seasons were less than r^2 values for separated seasons (ADD 0.7652; PMI 0.7677). In contrast to other studies, seasonality influenced the ADD model and PMI. Linear regression formulae for ADD and PMI as well as 95% confidence interval charts for TBS for ADD were developed. These equations, along with data from a local weather station, can be used to estimate the PMI with relative accuracy.

ABSTRAK

Verskaffing van 'n vermoedelike identifikasie van erg ontbinde of skeletale oorskot is die verantwoordelikheid van ‘n forensiese antropoloog. ‘n Belangrike deel van identifikasie is die beraming van ‘n post-mortem interval (PMI) vir die oorledene. Hierdie inligting verskaf 'n venster tydperk van dood, verminder die aantal potensiële slagoffers, sluit moontlike aanvallers uit en ondersteun getuienis. As gevolg van 'n groot aantal relatief verlate en oop velde in Suid-Afrika, word menslike oorskot dikwels aangetref in ‘n gevorderde stadium van ontbinding. Die doel van hierdie studie was om die bruikbaarheid van die metode van Megyesi en medewerkers (2005) wat gebruik maak van Totale Liggaams Telling (TLT) en Opgehoopte Graad-Dae (OGD) om die post-mortem interval (PMI) te skat, terugwerkend te evalueer. Hiervoor was 'n longitudinale studie van kwantitatiewe veranderlikes, TBS en ADD, oor ‘n tydperk van 8 maande gedoen. Hierdie tydperk sluit beide somer en winter in. Verspreidingsgrafieke tussen TBS en PMI, en TBS en ADD is gebruik om patrone in ontbinding te illustreer. Ontbindingspatrone het verskil tussen winter en somer met duidelike onaktiwiteit in die winter. Logliniêre Tweekansige-effek Maksimum Waarskynlikheid Regressie was gebruik om die r^2 waardes van die gekombineerde en geskeide seisoene te bepaal. The r^2 waardes vir die OGD (0.6227) en PMI (0.5503) vir gekombineer seisoene was minder as die r^2 waardes vir seisoene apart (OGD 0.7652; PMI 0.7677). In teenstelling met ander studies, het seisoenaliteit die OGD model en PMI beinvloed. Lineêre regressie formules vir OGD en PMI sowel as 95% vertrouensinterval kaarte vir TLT vir OGD was saamgestel. Hierdie formules saam met data vanaf ‘n plaaslike weerstasie kan gebruik word om die PMI met relatiewe akkuraatheid te skat.

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Chapter 1: Introduction

Providing a presumptive or positive identification of badly decomposed or skeletonized remains is the responsibility of a forensic anthropologist (Owsley 1993). A variety of information can be obtained from a decomposed body, including the post-mortem interval (PMI), which is useful when trying to establish a window period for death, to reduce the number of potential victims, to exclude possible assailants and to substantiate witness testimony (Megyesi *et al.*, 2005).

South Africa has been perceived as one of the most violent countries in the world (Norman *et al.*, 2007), due to its increasingly large number of unnatural deaths when compared to Western countries such as the United States or Europe. The leading cause of non-natural death in the country is homicide (46%) while motor vehicle accidents (26%), suicide (9%), and fire (7%) are also prominent (Norman *et al.*, 2007). Deaths associated with homicide contribute to 113 per 100,000 in males, 21 per 100,000 in females, and 65 per 100,000 overall each year. For males between 15 and 29 years of age, interpersonal violence has been shown to be responsible for 184 per 100,000 deaths (Norman *et al.*, 2007). Natural deaths, such as tuberculosis, AIDS, influenza and pneumonia (Statistics South Africa, 2009) affect forensic case numbers as many unknown persons died due to either exposure and/or untreated medical concerns. Due to the lack of medical care in these cases, bodies may not be discovered for a long period of time. Under these circumstances the decomposition may be to such an extent that the cause of death can not be determined by a pathologist.

The existence of many large open fields in the country, in which either a destitute person seeks refugee or a criminal chooses to deposit a body, results in human remains frequently being discovered in an advanced stage of decomposition. Limited information is available regarding the context in which the remains were discovered. Police reports often include the date of discovery, the location of the body, and the visual appearance of decomposition upon arrival. Using this information, data on the temperatures in the region of discovery can be collected and used in combination with the visual state of decomposition to provide an estimation of the post-mortem interval (Megyesi *et al.*, 2005).

Since 1993, the South African Police Service and various Medico-Legal Laboratories throughout the country have referred unidentified cases involving decomposed human remains to the Department of Anatomy, University of Pretoria for anthropological analysis. Most of these cases are in a state of advanced decomposition or badly burned (Steyn *et al.*, 1997). Currently, approximately 60 to 80 cases are received each year.

Research involving PMI estimations is crucially important to the forensic field. This is clearly demonstrated by the numerous studies that have already been done on human and non-human remains as well as the establishment of the Anthropology Research Facility in Knoxville, Tennessee (established in 1981) which is devoted to studying the decomposition process (e.g., Mann *et al.*, 1990; Bass, 1997; Rodriguez, 1997; Christensen, 2006).

Many researchers have described the changes that take place during the process of decomposition (e.g., Bass, 1997; Clark *et al.*, 1997; Galloway, 1997). However, these descriptions are qualitative in nature and can only help to establish wide maximum time estimates due to variation in environmental conditions (Megyesi *et al.*, 2005). Furthermore, many of the studies on decomposition varied as far as the seasons in which the study was conducted, the climate of the region, the methodology applied, and the species that were used. While some of these studies are longitudinal in nature or laboratory based, others are retrospective and may lead to data that is not standardized and thus not easily repeatable (Simmons *et al.*, 2010). There is thus a need for quantitative methods that can produce post-mortem interval estimates applicable to varying geographical regions and seasons. A number of such quantitative studies, which used decomposing pig carcasses to evaluate time since death (TSD), have been done in South Africa (Van der Linde and Leipoldt, 1999; Kelly, 2006); however, these studies focused more on the use of entomological evidence to determine the PMI than on the stages of decomposition. In North America there have been a number of studies involving the use of quantitative methods to determine the PMI from decomposed remains in a forensic anthropological aspect such as the research done by Vass and colleagues (1992), Megyesi *et al.* (2005) and Adlam and Simmons (2007). However, the study by Vass and associates (1992) did not focus on the appearance of decomposition to estimate PMI, but rather tested the applicability of soil solutions to estimate PMI. Alternatively, Adlam and Simmons (2007) applied the method developed by Megyesi *et al.* (2005) to test the effect of an external variable, such as physical disturbance, on the rate of decomposition.

These above-mentioned studies made use of temperature units, known as Accumulated Degree-Days (ADD), to quantify the rate of decomposition. ADD are heat energy units which represent the accumulation of thermal energy that is needed for chemical and biological reactions to take place in a body during decomposition and thus represent chronological time and temperature combined (Simmons *et al.*, 2010). Simmons and colleagues (2010) explained this concept by stating that ADD measures the energy that is placed into a system as accumulated temperature over time and thus when an equal amount of thermal energy (ADD) is placed into a carcass, an equal amount of reaction (decomposition) is to take place. By making use of ADD, the effect of temperature in multiple regions can be eliminated thereby allowing different studies to be compared with each other (Simmons *et al.*, 2010). To calculate ADD, the maximum and minimum temperature of the day is averaged to produce the mean daily temperature which is also the ADD for the specific day.

The study of Megyesi and colleagues (2005) is unique in that it incorporated both qualitative and quantitative data to provide an estimate of PMI. The foundation of this method involved the conversion of the qualitative data of decomposition (i.e. descriptions of the stages) into quantitative scores from three different regions of the body, namely the head and neck, trunk and limbs. The allotted point values for each region are then added to produce a Total Body Score (TBS). The TBS is the decomposition stage expressed in terms of a quantitative score that can be used in statistical calculations such as linear regression analysis. The use of ADD may be useful in the global application of this technique in that knowledge of temperature can be used to adjust time scales for the post-mortem interval.

However, it is not known whether this method is usable across various geographical regions and climatic conditions, and research is needed to assess the repeatability of this research and the reliability and validity of the method. The descriptions of the state of decomposition may vary between individuals, different climates and different fauna (specifically insects), and the effects of other variables, such as humidity, should be taken into account. Due to the retrospective nature of the study by Megyesi and colleagues (2005) certain scores or data entries may have been absent or not clearly visible, whereas a longitudinal study allows for the data to be more complete, as well as more accurate with regard to collection and scoring. Should these above mentioned methods prove to be reproducible and accurate in a South African setting, the post-mortem interval may be estimated for many forensic cases thereby providing further assistance in the process of identification.

The aim of this study was to evaluate the usability of the method of Megyesi and associates (2005) in which Total Body Score (TBS) and Accumulated Degree-Days (ADD) were retrospectively applied to estimate the post-mortem interval (PMI). To achieve this purpose, a longitudinal examination of quantitative variables, TBS and ADD, was conducted over a period of 8 months. This period included both summer and winter seasons. Scatter plots between TBS and PMI, and TBS and ADD were used to demonstrate patterns in decomposition. New formulae for the South Africa were developed.

Chapter 2: Literature Review

2.1 The biological process of decomposition

All living organisms are dependent on highly organized chemical processes that occur throughout life. These reactions are well-catalyzed and segregated within specific locations in the body such as the membranes of the various organelles and cells. It appears that after death these chemical processes are still evident in the human body but become more disorganized as the cells are deprived of oxygen (Gill-King, 1997). This leads to an increase of carbon dioxide in the tissues and blood, and a decrease in intra-cellular pH and accumulation of waste products (Cotran, 1994; Vass, 2001). Ultimately the cells start to die off due to self-digestion, also known as autolysis or aerobic decomposition, and the nutrient-rich fluids of the cells are released into the surrounding tissues (Clark *et al.*, 1997; Gill-King, 1997; Vass, 2001).

In central metabolic pathways, energy is stored in the form of phosphate bonds in ATP (adenosine triphosphate). These bonds are used to fuel numerous chemical reactions that are necessary to sustain life. When this production of ATP, of which the electron transport chain is the most prominent, fails, biosynthesis and cellular repair can no longer occur (Gill-King, 1997). Autolysis is brought about by the decline of intra-cellular pH due to the failing of the buffer systems in the cells and blood (Cormack, 1987; Gill-King, 1997). This causes a shift from the central metabolic pathway to one of fermentation (Gill-King, 1997).

The failure of ATP production and thus cellular biosynthesis and repair, results in the loss of membrane structures that are required to regulate molecular transport. This breach in membrane integrity causes intra-cellular contents to seep out through the cellular membrane into the surrounding tissues. Thus, hydrolytic enzymes are released from previously compartmentalized organelles such as the lysosomes. Autolysis is the final result of the digestion of carbohydrates and proteins as well as the remainder of the membrane by hydrolytic enzymes, cellular necrosis and the detachment of cells from one another (Clark *et al.*, 1997; Gill-King, 1997). The molecules released from these digested cells are further utilized by micro-organisms, located in various parts of the body, as nutrients (Clark *et al.*, 1997). Like all chemical reactions, autolysis is also influenced by various factors such as cell type and temperature. In general, autolysis occurs first in cells that are more metabolically active, have high water content and have high rates of ATP production, as well as cells that contain large numbers of lysosomes or other hydrolytic enzyme stores (Clark *et al.*, 1997; Gill-King, 1997; Vass, 2001). Furthermore, if the temperature of the body is low, the onset and rate of autolysis will be retarded while higher temperatures, whether caused by the ambient air temperature, fever or high levels of exertion prior to death, will accelerate the rate and onset of autolysis (Clark *et al.*, 1997).

The changes produced by autolysis are usually only visible several hours after death. The first observable changes are the appearance of fluid-filled blisters on the skin followed by skin slippage due to the loss of dermal-epidermal junctions such that the hair and nails dislodge and fall off (Clark *et al.*, 1997; Vass, 2001). Other changes associated with autolysis that occur during this early stage of decomposition include cooling of the body (*algor mortis*), pooling of the blood (*livor mortis*), and stiffening of the muscles (*rigor mortis*) (Vass, 2001).

2.1.1 Algor Mortis

After death the body no longer produces heat and starts to cool by the actions of radiation, convection, conduction and evaporation (Pounder, 2000; Tracqui, 2000). Chemical reactions within the body occur near 37ºC and cooling of the body will influence the rate of metabolism by affecting the activity of enzymes that act as cellular catalysts (Gill-King, 1997). Algor mortis, or body cooling, is thus the most useful method to apply when estimating the PMI within the first 24 hours after death.

Previously, PMI was roughly estimated by assuming that the body cools 1ºC every hour during the first 24 hours (Tracqui, 2000). This implies that body cooling is a linear function of time; however, Newton's Law states that an object's rate of cooling is determined by the difference between the environmental temperature and the temperature of the object. A plot of temperature against time will thus result in an exponential curve. Since a body generally has a large mass, an irregular shape and tissues with different physical properties, the cooling of a corpse is more complex and is best represented by a sigmoid curve (Marshall and Hoare, 1962; Henssge *et al.*, 1995; Pounder, 2000; Tracqui, 2000). When temperature is plotted against time, three distinct periods can be identified: (1) the initial phase or temperature plateau when the temperature remains relatively stable for 30 minutes to three hours; (2) the intermediate phase in which the body cools rapidly and at a relatively linear rate and; (3) the terminal phase when the rate of body cooling slows as the core temperature reaches equilibrium with the environmental temperature (Pounder, 2000; Tracqui, 2000).

The PMI cannot be accurately estimated during the first three to five hours after death due to the effect of the actual body temperature at death and the length of the temperature plateau following death. Similarly, PMI cannot be calculated from body cooling when the body temperature reaches equilibrium with the environmental temperature (Pounder, 2000). In cases where the body temperature is subnormal (death from hypothermia, shock or massive haemorrhage) or raised (death after an intense struggle, in heat stroke or fever), an error may occur in the PMI when using algor mortis. Also, the estimations used to calculate the PMI assume that the environmental temperature remains constant, which is not often the case. For these reasons, the intermediate phase is used to give reasonably reliable estimates of the PMI by applying any formula that involves averaging the decline of temperature per hour (Pounder, 2000; Tracqui, 2000). Other factors that influence the linear rate of body cooling during the intermediate phase include body size, clothing and coverings, humidity, air movement and immersion in water. Accourding to Tracqui (2000), the best tested method currently available for estimating the PMI from a cooling body is that of Henssge (1988).

2.1.2 Livor Mortis

Livor mortis or lividity is caused by the gravitational settling of the red blood cells and blood plasma within the lowest levels of the vascular system. The capillary and venous beds become relaxed after death and the blood travels passively from high to low areas of pressure. The plasma causes oedema in the skin, which ultimately contributes to the cutaneous blisters of this early phase of decomposition (Knight, 1997; Pounder, 2000; Tracqui, 2000).

The characteristic staining of the skin from livor mortis is caused by the settling of the red blood cells in the lower areas of the body because of gravity. The skin starts to form pink or bluish zones in these areas within one to four hours after death; however, regions of the body that are in contact with hard surfaces form only pale patches of colour. This is a consequence of pressure from the supporting surfaces that prevents the pooling, or settling, of blood in that area (Knight, 1997; Pickering and Bachman, 1997).

The colour of the lividity phase is variable and generally becomes visible within three to four hours after death. As the time since death elapses, it often changes from dark pink to red to purple and the maximum colour intensity can be seen around eight to twelve hours after death (Tracqui, 2000). This colour change results from the dissociation of oxygen from the haemoglobin molecule, which forms a purple pigment, deoxyhaemoglobin. Approximately twelve to fifteen hours after death livor mortis becomes permanent and remains visible until the onset of putrefaction (Clark *et al.*, 1997; Pounder, 2000; Tracqui, 2000).

2.1.3. Rigor Mortis

Immediately after death, the muscles of the body lose the ability to contract resulting in complete flaccidity of the body; yet, within a variable time period they become stiff again due to a complex set of physiochemical changes (Knight 1997, Traqui, 2000). After death, the sarcoplasmic reticulum in the muscle cells loses its integrity and calcium ions flood into the sarcomere. Here, the calcium unblocks the binding sites on the actin, allowing it to bind to myosin causing the muscles to stiffen or become rigid. Normally, ATP-driven active transport reverses this reaction by pumping the calcium back into the sarcoplasmic reticulum to cause relaxation. Since ATP production ceases after death, the state of contraction persists as rigor mortis until the actin molecules are dissociated from the ends of the sacromeres by proteolytic enzymes located in the muscle cells, thereby causing the rigor to reverse (Koomaraie *et al.*, 1991; Wheeler and Koohmaraie, 1991; Whipple and Koohmaraie, 1991; Marieb, 1992; Knight, 1997).

Rigor mortis appears in a predictable sequence and follows a pattern known as Nysten's Law (Tracqui, 2000). Rigor appears first in the small muscles of the face (i.e., the muscles of the eyelids and lower jaw), then spreads to the muscles of the neck, trunk, upper limbs and lastly, the muscles of the lower limbs (Green, 2000; Tracqui, 2000).

The onset and duration of rigor mortis is highly influenced by temperature and the degree of muscular development and muscular activity prior to death. High temperatures will result in a rapid onset and short duration of rigor, while low temperatures delay the onset of rigor but lengthen its duration. Furthermore, excessive muscular activity prior to death will result in a rapid onset of rigor because greater amounts of lactic acid are available in the recently active muscles. In children and elderly individuals the onset of rigor mortis is rapid with a short duration and has a subdued intensity due to poor muscle development. Individuals with a higher lean body mass tend to exhibit rigor more intensely (Knight, 1997; Pounder, 2000; Green, 2000; Tracqui, 2000).

2.1.4. Putrefaction

Autolysis is only one of the major components of decomposition and essentially fuels the next process, putrefaction or anaerobic decomposition, by providing nutrients as well as an anaerobic environment in which the micro-organism within the body can flourish (Clark *et al.*, 1997; Gill-King, 1997; Vass, 2001). While autolysis is active on the microscopic level, putrefaction causes the most dramatic soft tissue changes in a decomposing body (Clark *et al.*, 1997; Pinheiro, 2006).

This destruction of the soft tissues is caused by the action of micro-organisms (for example bacteria, fungi, and protozoa as well as endogenous enzymes) within the large bowel. These organisms are responsible for the degradation of carbohydrates, proteins, and fats resulting in the formation of various gases (i.e., methane, hydrogen, and hydrogen sulphide), liquids, salts and acids (Morse *et al.*, 1983; Vass 2001). These products are responsible for the characteristics of the early putrefactive stages such as bloating, colour changes and odour formation (Gill-King, 1997; Vass 2001).

The earliest sign of putrefaction is the appearance of a green discolouration of the skin that begins in the right lower section of the abdomen (right iliac fossa) in the region of the caecum. This discolouration then spreads to the rest of the abdominal wall, the trunk, neck, face and lastly to the limbs (Green, 2000; Traqui, 2000; Vass, 2001). This phenomenon is caused by the breakdown of blood to sulph-haemoglobin, which has a green-purple colour, that accumulates in the tissues and then gradually changes to black. This discolouration is especially noticeable in the superficial blood vessels and results in the skin having a marbled appearance (Gill-King, 1997; Green, 2000).

Other changes during early decomposition include skin blisters, and gaseous swelling (associated with anaerobic fermentation) of the trunk, abdomen and scrotum. This rise in the internal pressure ultimately results in the protrusion of the tongue and eyes as well as the expulsion of the accumulated gases and fluids from the nose (lung purges), mouth (stomach purges) and anus and the skin starts to slough off (Knight, 1997; Green, 2000; Vass, 2001). It is during this stage that a great degree of insect activity in the form of maggots is often observed. Maggots account for the largest amount of destruction to the soft tissues compared to any other organisms mentioned (Simmons *et al.*, 2010).

Later on during putrefaction the exposed parts of the body that have not been consumed by maggots start to turn black and the abdomen and trunk collapse due to purging. The tissues of the eyes and throat cave in, mould proliferates and spreads over the body, and skeletal remains become exposed as muscle tissue is broken down. This continues until the body is completely skeletonized (Traqui, 2000; Vass, 2001; Megyesi *et al.*, 2005).

2.1.5. Post-skeletal decomposition

After skeletonization, decomposition continues to break down the organic (collagen) and inorganic (bioapatite) components of bone, which causes mechanical and chemical changes in the bone surface as well as the subsurface (Behrensmeyer, 1978). According to Collins and associates (2002), three pathways of destruction can occur to bone, namely: (1) the chemical deterioration of the organic phase where glycation reactions cause the collagen to become more brittle and lead to a change in the organization, gelatinization and ultimately the loss of collagen in the bone (Collins *et al.*, 1995; Bailey *et al.*, 1998; Collins *et al.*, 2002); (2) the chemical deterioration of the mineral phase due to the kinetics of dissolution/re-precipitation (Collins *et al.*, 2002); and (3) the (micro)biological attack of the composite via extracellular microbial enzymes (Collins *et al.*, 2002).

Weathering is a term that describes the destruction of the bone due to environment-related processes and erosion (Janjua and Rogers, 2008). The sequence of weathering was previously described by Behnrensmeyer (1978). Initially the bone is greasy but then it starts to develop cracks that are longitudinal to the fibre structure found in the bone. The cortex starts to flake; one edge of the flake stays attached to the bone while exfoliation is observed on the outer cortical layer. As time progresses, the bone surface becomes rougher, the cracks deeper, and loose splinters are found attached to the outer structure. These destructive forces then penetrate the inner areas of bone until it becomes fragile and starts to fall apart (Behnrensmeyer, 1978).

2.1.6 Modifications to decomposition

There are numerous factors (e.g., temperature) that can influence the rate at which the above-mentioned changes in decomposition occur and even though the sequence of decomposition remains relatively stable, inter-subject variability exists (Traqui, 2000). This means that certain changes associated with the advanced stages of decomposition may appear earlier in the process. Furthermore, a number of modifications to decomposition, most commonly adipocere formation or mummification, may take place due to the effect of the environment on the tissue components of the body (Clark *et al.*, 1997; Traqui, 2000).

Adipocere formation or saponification (the formation of soap from the lipids in the body at a high pH) results from the hydrolysis of body fats with the release of fatty acids. This process usually occurs in warm, damp, and preferably anaerobic environments. During early formation the adipocere has a yellowish-white colour and a firm greasy and wax-like consistency. However, as time passes, the adipocere becomes lighter in colour, harder and brittle (Hugland, 1993; Clark *et al.*, 1997; Green, 2000; Pounder, 2000; Vass, 2001).

Mummification most commonly occurs in areas with dry heat and hot, dry air currents or just low humidity (e.g., the arctic region, the desert and buildings with hot-air heating). This process is also promoted by the absence of insects and other scavengers. Modifications of mummification include shrivelling of the body and the organs due to dehydration, and the skin may become leathery, dark and parchment-like skin that, along with the tendons, tends to cling to the skeletal structure (Clark *et al.*, 1997; Green, 2000; Pounder, 2000; Vass, 2001).

2.2 Decomposition studies

2.2.1 A brief history on decomposition studies

A large number of studies have been conducted on a variety of topics related to taphonomy. Taphonomy is the field of study concerned with the post-mortem processes that affect the preservation, observation, and recovery of deceased organisms, the reconstruction of their biological environment as well as the circumstances surrounding death (Haglund and Sorg, 1997).

Forensic taphonomy is a sub-discipline of this field concerned with reconstructing the events that took place after death as a means to better interpret traumatic injury on bone, time since death, post-mortem carnivore activity as well as the cause and manner of death of the individual (Dirkmaat *et al.*, 2008). Forensic anthropologists are keen to investigate changes in decomposition rates as the majority of bodies referred to an anthropologist are in an advanced stage of decomposition such that other available methods for establishing time since death, such as algor mortis, are no longer reliable and/or applicable.

Numerous anthropological studies on the rate of decomposition of an organism in varying environmental conditions (e.g., hot, humid, dry and cold) as well as in different situations and accessibility (e.g., exposed, buried, burned) have been conducted in the United States (e.g., Galloway *et al.*, 1989; Mann *et al.*, 1990; Bass, 1997; Rodriguez, 1997), Canada (e.g., Komar, 1998), England (e.g., Aslam and Simmons, 2007), and Australia (e.g., Archer, 2003). Decomposition studies have included a wide variety of mammalian models such as dogs (Reed, 1958), guinea pigs (Bornemissza, 1957), rabbits (Johnson, 1975; Adlam and Simmons, 2007), pigs (Payne, 1968; Blair *et al.*, 1993; Shalaby *et al.*, 2000) and humans (Rodriguez and Bass, 1985; Mann *et al.*, 1990; Vass *et al.*, 1992). A significant portion of the published material on human remains originated from the Anthropology Research Facility in Knoxville, Tennessee, established in 1981, which was the first facility in which the processes of human decomposition as well as the factors influencing this process have been thoroughly studied (Bass, 1997; Shahid *et al.*, 2003; Bass and Jefferson, 2004).

According to Mann and colleagues (1990), the setbacks for establishing this kind of research centre include difficulty in obtaining bodies to study, the lack of suitable areas to place the bodies as well as the negative opinion, limited knowledge and the lack of interest from the public. These issues are less applicable in the 21st century as numerous facilities and studies are being carried out internationally, namely the decomposition facilities at the University of Lancastershire in England and Texas State University in the USA. However, various other properties such as experimental terrain, woodlands and farms from surrounding areas are also used for this propose. For example Wagster (2007) and Parsons (2009) made use of the Lubrecht Experimental Forest in Montana; Bunch (2009) used the Rice Creek Field Station outside of the State University of New York; and Schiel (2008) conducted her study in a field at the Iowa State University and a farm in Rensselaer, Indiana. The increase in regions, location and geographic areas for decomposition research present a wealth of descriptive data but due to inconsistencies in scoring methods and statistical analyses make the results difficult to repeat, compare and validate.

The degree to which external factors influence the rate of decomposition varies between geographical regions; for this reason studies on decomposition rate are needed in each geographical area throughout a particular country (Mann *et al.*, 1990; Pinheiro, 2006). With geographically specific data, models can be created for ascertaining the PMI in a variety of circumstances and environmental locations (Adlam and Simmons, 2007).

As with any research field, studies designed to investigate the rate of decomposition use standard terminology, definitions and methodology. However, unlike most other research fields, no definitive standards for measuring decomposition rates have been established. Therefore, a brief discussion on methodology, standards and the techniques used to determine PMI is necessary.

Researchers have developed several qualitative and quantitative methods to determine PMI that are focused on defining the stages of decomposition, their time intervals (Payne, 1965; Johnson, 1975; Rodriguez and Bass, 1983; Galloway *et al.*, 1989; Bass, 1997; Clark *et al.*, 1997; Galloway *et al.*, 1997; Megyesi *et al.*, 2005) and the degree to which various factors influence the rate of decomposition (Micozzi, 1986; Mann *et al.*, 1990; Hewadikaram and Goff, 1991; Shean *et al.*, 1993; Micozzi, 1997; Komar, 1998; Shalaby *et al.*, 2000; Archer, 2004).

2.2.2 Qualitative research on the PMI

Qualitative decomposition research focuses on observations and interpretations of remains placed in various settings and geographical locations. The major problem with qualitative studies is that they are descriptive in nature and not necessarily repeatable. Observing the state of the body and the amount of time needed to reach this state of decomposition results in PMI estimates based on personal opinions, experience and knowledge of the climate surrounding the area where the body was found (Haglund and Sorg, 1997). Differences in the terminology or descriptions in the phases as well as the time intervals between stages, result in further confusion on the true time since death (TSD) for a specific body (Haglund and Sorg, 1997; Haglund and Sorg, 2002). Ideally the data collected must be comparable to other cases and the data should be a presentation of the model that is used thereby increasing the repeatability of the results (Haglund and Sorg, 2002).

Available literature involves studies that focus on trying to more accurately define the stages of decomposition (Weigelt, 1927; Reed, 1958; Galloway *et al.*, 1989; Vass *et al.*, 1992). In 1927, Weigelt suggested that the process of decomposition needs to be divided into three stages, namely fresh, bloated, and putrefaction. Later, Reed (1958) defined an extra stage, resulting in four phases: fresh, bloated, decay and dry. Vass and associates (1992) however, divided decomposition into two major stages: 1) preskeletonization which is subdivided into the four stages as outlined by Reed (1958); and 2) postskeletonization which includes extreme changes affecting the already dry bones e.g., weathering. Galloway (1997) added a fifth stage, thereby incorporating continued decomposition of dry bone. This stage is known as extreme decomposition and is associated with skeletal remains left undisturbed for months after skeletonization has taken place. This stage is not included in many modified versions of Galloway's method (Megyesi *et al.*, 2005) probably due to the long period of time that is needed to reach this stage (Bass, 1997).

Modifications to the first four stages were made as the number of decomposition studies increased. Several authors (Micozzi, 1991; Clark *et al.*, 1997; Galloway *et al.*, 1997) developed categories within each stage resulting in further variation in the classification of the processes of decomposition. These studies were done in different geographical locations causing even more variation since the temperature, humidity, and carnivore activity vary considerably between these areas (Mann *et al.*, 1990; Megyesi *et al.*, 2005). Furthermore, the degree to which the rate of decomposition differs between studies causes a major overlap in the TSD estimations. There have been reports of bodies almost reaching the stage of complete skeletonization within 10 days due to extreme insect infestation (Steward, 1979), while other bodies may appear reasonably fresh and intact but have a PMI of a couple of years. An excellent example of this is the famous case of Colonel Shy whose body was embalmed and buried in an iron coffin. The cause of death was determined to be due to a gunshot wound to the head. The body had soft tissue adhered to the bones and the clothing was intact. This resulted in a time since death estimation of about a year, but it was later determined that the body belonged to Colonel William Shy who had died 113 years prior to the discovery (Owsley and Crompton, 1997; Bass and Jefferson, 2004). This large underestimation was because of a disruption in decomposition process due to a combination of external variables, namely the burial, the sealed iron coffin and embalming fluid. These conditions led to a delay in onset of fermentation and putrefaction and prevented the influence of external environmental factors and insect accessibility (Owsley and Crompton, 1997). This clearly demonstrates the tremendous need for decomposition studies focused on the discovery of methods to estimate the PMI with a high level of accuracy and to better understand the processes and variables involved in the rate of decomposition (Parkinson *et al.*, 2009; Parsons, 2009).

As the number of studies increased, new stages were added and the terminology used to define these specific stages changed. This variation is demonstrated in Figure 2.1, which summarizes the number and time of onset of each decomposition stage (Adlam and Simmons, 2007). In this visual summary each defined stage is represented by a specific shade, except for Clark and researchers (1997) where the stages were further subdivided by solid bars within the shaded areas.

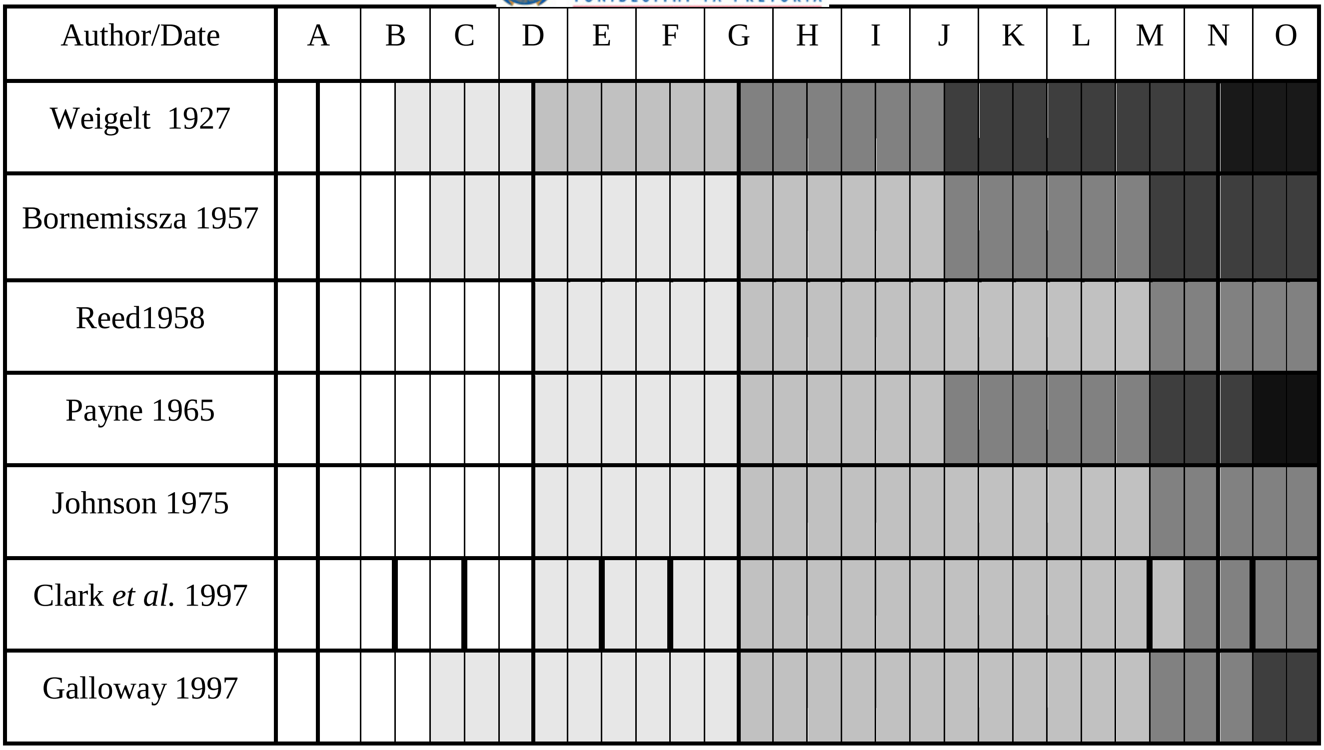

Figure 2.1. Comparison of decomposition stages where each shade represents a phase or category of decomposition A = Fresh; B = Pink; C = Green; D = Bloat; E = Brown; F = Moist; G = Bloat lost; H = Maggots; I = Tissue loss; J = Drying; K = Mummification; L = Adipocere; M = Bone exposure; N = Skeletonization; O = Bone destruction (taken from Adlam and Simmons, 2007).

When describing the early stages of decomposition, researchers have remained consistent with the definition and sequence of stages. However, as decomposition advances this uniformity is lost and the stages can no longer be separated or defined as easily as during the early stages (Adlam and Simmons, 2007). This is probably due to the decreased rate of decomposition and the overlapping of various characteristics during the later stages.

Nevertheless, from these various studies the rate of decomposition can be consistently divided into four main categories: fresh; early decomposition with bloating; advanced decomposition with active decay; and skeletonization or dry stage (Reed, 1958; Payne, 1965; Johnson, 1985; Vass *et al.*, 1992; Galloway, 1997). The differences in the stages within these four categories are largely due to the variation in the decomposition process brought about by the differences in the environments.

2.2.3 Quantitative research on the PMI

As mentioned earlier, using qualitative methods to estimate the PMI can be problematic due to the large amount of variation in the decomposition process, the differences in the experience of forensic anthropologists and the discrepancy in the descriptions of the stages of decomposition (Mann *et al.*, 1990; Haglund and Sorg, 1997; Megyesi *et al.*, 2005). The qualitative methods frequently employed by forensic anthropologists often produce rather rough PMI estimates with large ranges indicating the minimum and maximum time estimates since death (Megyesi *et al.*, 2005). However, other disciplines such as forensic entomology and botany make use of more quantitative methods to estimate the PMI (Catts and Goff, 1992; Hall, 1997; Haskell *et al.*, 1997). The research done by Vass *et al.*, (1990) and Megyesi and colleagues (2005) provide encouraging results using Accumulated Degree-Days (ADD) to quantify decomposition processes.

Vass and researchers (1990) studied the use of the concentrations of volatile fatty acids (produced from the decomposition of soft tissues) that are deposited in the soil solution beneath the body during the decomposition period to estimate the TSD. The results from this research indicated that decomposition of soft tissues and thus fatty acid production ceases by approximately 1285 ADD and skeletonization occurs thereafter (Vass *et al.*, 1990).

In contrast, Megyesi and associates (2005) made use of qualitative data (stages of decomposition) as well as quantitative data (ADD). In order to convert this qualitative data into quantitative data, the stages of decomposition for the three anatomical regions (head and neck, trunk and limbs) were scored and these values were added to produce the Total Body Score (TBS). Using this value, in conjunction with ADD, result in fairly accurate PMI estimations. The results from this study support the observations from Vass and researchers (1990). Megyesi *et al.* (2005) concluded that approximately 80% of the variation in the decomposition process is due to ADD and that decomposition should be modeled as dependant on the accumulated temperature rather than just the elapsed time.

2.2.4 Factors influencing decomposition

Several factors and/or circumstances can influence the rate, the sequence and the morphology of decomposition (Mann *et al.*, 1990; Bass, 1997; Adlam and Simmons, 2007). This results in anomalies in qualitative as well as quantitative studies of decomposition. Mann *et al.* (1990:104) stated that time since death estimations can seldom be made using a single variable - since several factors are interrelated, isolating a single variable will only provide a “tiny piece of a biased puzzle.”

The geographical area where a study is performed will largely influence the number of stages used and the time required to reach each stage. For example, adipocere or mummification, which depends on the humidity and temperature of the environment, may or may not be included within the research categories for decomposition (Galloway, 1997; Megyesi *et al.*, 2005).

Mann and associates (1990) studied a number of variables that are known to have an effect on the rate of decomposition. They rated these variables using a five-point scale to demonstrate the relative importance of each on the decomposition process. Table 2.1 lists the variables in order of the greatest to the least influential according to Mann *et al.*, (1990). Similarly, Galloway and colleagues (1989), Adlam and Simmons (2007), Nawrocki (2009) and Simmons *et al.* (2010) found three variables that consistently had the largest influence on the rate of decomposition: temperature, accessibility by insects and moisture or humidity. Therefore burial depth and access by insects can be considered together since burial of a body ultimately hinders insect accessibility (Rodriguez and Bass, 1985).

These variables are divided into 5 main levels, with each level indicating factors that have the same degree of influence. From Table 2.1, it is clear that variables such as temperature and insect accessibility will have a much greater influence on the rate of decomposition than the lower level variables such as clothing and the surface the body was placed.

Table 2.1. Variables affecting the decay rate of a human body (taken from Mann *et. al.*, 1990).

Variable	Effect on Decay Rate[a]
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
Soil pH	unknown

[a]Subjective criteria rating based on a five-point scale, 5 being the most influential.

Nawrocki (1995) divided the various factors into three categories: (1) **Environmental factors** which is subdivided into abiotic (nonliving) environmental factors such as temperature, rainfall and sun exposure and biotic (living) environmental factors such as carnivore and rodent activity as well as botany; (2) **Individual factors** which are intrinsic to the body such as body size; (3) **Behavioral or cultural factors** caused by human activity such as burial or the removal of body parts.

Due to the subjectivity of the variables to the region, Galloway (1997) suggested that temperature and humidity be considered together in arid regions since the two variables are inextricably related (Mann *et al.*, 1990; Vass *et al.*, 1992). Consequently, different studies have been done to determine the influence these factors have on the process of decomposition, in some cases independently and in others as part of an observation of a larger study. The variables affecting decomposition will be discussed using five categories namely insect access, viability and activity, environmental variables, the location of the body, carnivore and scavenger activity and the physical appearance of the body.

2.2.4.1 Insect access, viability and activity

Feeding of insect larvae on the carcass causes the greatest amount of soft-tissue destruction during decomposition (Mann *et al.*, 1990; Haskell *et al.*, 1997). If insect activity should be prevented, the rate of decomposition will significantly decrease. Also, the outcome and stages of decomposition may become altered as in the case of mummified tissues. There are many factors that have an influence on the rate of decomposition; however, it appears that some of these will influence the rate of decomposition indirectly by altering the activity and viability of the insects in the region of the body (Galloway *et al.*, 1989; Mann *et al.*, 1990; Haskell *et al.*, 1997; Campobasso *et al.*, 2001). It is for this reason that studies on decomposition often involve reference to entomological research and the effect of various other factors on insect activity and thus rate of decomposition will be discussed in their separate sections.

2.2.4.2 Environmental variables

The environment has the most obvious influence on the decomposition process since the temperature, humidity and rainfall, unlike the other factors that can be controlled, are highly variable and constantly influencing the decomposing organism (Mann *et al.*, 1990; Bass, 1997; Galloway, 1997; Komar, 1998; Archer, 2004).

2.2.4.2.1 Temperature

The ambient temperature has the greatest influence on the rate of decomposition because many biological processes occur at specific temperatures e.g., enzymes have optimum activity at certain temperatures depending on the type and location of the enzyme (Sheridan *et al.*, 2000). The temperature at which biological processes no longer take place is known as the base temperature (Megyesi *et al.*, 2005). The base temperature at which decomposition ceases is not known and different values have been suggested. Forensic entomologists use 10˚C or 6˚C depending on the fly species, while forensic anthropologists have suggested that the decomposition base temperature may be lower (Megyesi *et al.*, 2005). Vass and researchers (1992) recommended a base temperature of 0˚C since the salt concentrations in the human body are sufficient in sustaining processes involved in decomposition and autolysis. Thus, temperature values lower than 0˚C are not calculated as a negative number, because the process of decomposition can only be stopped and not reversed (Vass *et al.*, 1992; Megyesi *et al.*, 2005). Micozzi (1991) stated that decomposition is severely hindered from temperatures of 4˚C and less due to the inhibition of bacterial growth. Furthermore, the activity and viability of the insects are influenced by the temperature and season (Mann *et al.*, 1990; Galloway, 1997; Campobasso *et al.*, 2001; Simmons *et al.*, 2010). For instance, the sarcophagids can only lay eggs at certain temperatures and amounts of sun exposure (sufficient sunlight during colder seasons and enough shade during extremely hot temperatures to ensure viability of the maggots) (Haskell *et al.*, 1997; Galloway, 1997). According to Mann and researchers (1990), fly eggs and larvae die at 0˚C outside the body but when within the body cavities, they thrive because they produce their own heat in large numbers. Researchers thus commonly accept that decomposition almost completely ceases at 0˚C since freezing is the most effective technique of preservation and any temperatures below zero are incompatible with biological processes (Micozzi, 1991; Megyesi *et al.*, 2005).

Prieto *et al.* (2004) suggested that the type of climate, seasonality and the temperature changes associated with the specific region have an influence on the rate of decomposition. Cadavers found in regions with more extreme seasonal changes in temperature (continental climate) have a slower rate of decomposition than those found in regions with more constant, warmer temperatures (littoral climate).

The effect of temperature on the rate of decomposition has formed the focus of numerous studies (e.g., Micozzi, 1986; Micozzi, 1997; Komar, 1998; Archer 2004) and has also been an important observation in other studies looking at different influencing factors on decomposition (Galloway, 1989; Mann *et al.*, 1990; Vass *et al.*, 1991). These researchers propose that temperature cannot always be regarded as a factor on its own because other variables, such as humidity, are either dependant or co-dependent on temperature.

In general, the rate of decomposition increases with a rise in the ambient air temperature (with or without the formation of adipocere or mummification). Micozzi (1997:171) stated that even though the rate of decomposition is altered by temperature changes, the “fundamental character” of decomposition and the sequence of events remain unchanged. However, the freezing of tissue followed by thawing can greatly modify the processes involved in decomposition. Frozen-thawed corpses display a greater amount of external decay, predominantly autolysis, resulting from greater insect colonization and from invasion by external soil organisms and other aerobic bacteria. In contrast, the fresh specimens exhibit a greater degree of change in the internal viscera brought about by putrefaction. Micozzi (1997:177) summarizes this phenomenon by stating that previously frozen specimens display “outside-in” decomposition while fresh, unfrozen specimens decomposed from the “inside-out” (Micozzi, 1986; Micozzi 1991).

Other variables influenced by the environmental temperature include temperature of water during submersion and burials, scavenger activity, and insect viability/activity (Beckhoff and Wells, 1980; Rodriguez and Bass, 1985; Mann *et al.*, 1990; Boyle *et al.*, 1997; Rodriguez, 1997).

2.2.4.2.2 Humidity/Aridity

The amount of moisture in the environment, like temperature changes, can also influence the rate and the pattern of decomposition to a great extent. Humidity and aridity may arrest decomposition in that adipocere can form on the body (humid environments) or mummification can occur (dry environments). Unlike adipocere, however, mummification is not dependant on the temperature and can occur in hot or cold temperatures as long as the moisture content of the air is low (Mann *et al.*, 1990, Clark *et al.*, 1997; Vass, 2001).

Generally, humid environments result in an increased rate of decomposition due to the increased insect activity and viability since the larvae require a certain amount of moisture to survive (Galloway *et al.*, 1989; Mann *et al.*, 1990; Bass, 1997; Campobasso *et al.*, 2001). Bodies located in closed structures often decompose at a faster rate, though the onset of early decomposition may be delayed due to initial prevention of insect access. Thus, bodies retain a fresh appearance for a couple of days, however skeletal exposure or adipocere formation can occur rapidly thereafter due to extreme maggot activity and accelerated autolysis. If the closed environment has air ventilation resulting in evaporation of moisture, the body can become mummified since bacterial proliferation and insect activity is impaired (Galloway *et al.*, 1989; Campobasso *et al.*, 2001). Prieto and associates (2004) also observed an increased rate of decomposition in bodies recovered from coastal regions since the climate in these regions (characterized by high humidity with warm constant temperatures) favours the proliferation of micro-organisms involved in putrefaction. The results of these studies suggest that high humidity accelerates decomposition while extremely dry environments tend to slow down the rate of decomposition.

2.2.4.2.3 Rainfall

Not much research has been done on the effect of rain on the rate of decomposition and studies that mention the effect of rainfall have ambiguous results (Reed, 1958; Mann *et al.*, 1990; Archer, 2004). The effects of rainfall have not been statistically separated from those of temperature (Archer, 2004). As already mentioned, temperature and rainfall are co-dependent since rainfall often increases during the warmer months of the year while the actual rainfall lowers the temperature. Separating the effect of these two variables on the rate of decomposition as well as the activity of the insects involved is thus extremely difficult.

Reed (1958) and Mann and associates (1990) found that rainfall does not influence the activity of the maggots or flies and therefore the rate of decomposition was not influenced. The larvae, sheltered inside the cavities of the carcass were protected from rainfall and continued to feed. The fly activity, however, was reduced during moderate to heavy rainfall (Mann *et al.*, 1990). In contrast to this, Lopes De Carvalho and Linhares (2001) found that the adult insect activity and abundance was greatly influenced by the presence of heavy rainfall. This phenomenon was probably due to the negative impact of heavy rain on the fly abundance in the traps and these authors stated that the increased rate of decomposition may have resulted from the combination of higher temperatures, humidity and rainfall during the summer months (Lopes De Carvalho and Linhares, 2001).

Archer (2004) suggests that rainfall may increase the rate of decomposition in neonates by leaching into the tissues and thereby providing moisture for bacteria and larvae, thus preventing tissue desiccation. This creates an encouraging environment for maggot and bacterial action and increases mass loss by mechanically breaking-up of flesh. However, Archer (2004) also suggested that rainfall and soil moisture can potentially hinder decomposition due to the reduction of temperature via evaporative cooling and reduced mass loss due to increased water content (Early and Goff, 1986; Archer, 2004).

2.2.4.3 Location of Body

2.2.4.3.1 Burial depth and soil composition

Rodriguez and Bass (1985) studied the effect of burial depth on the rate of decomposition by placing cadavers into unlined trenches at depths of 30 cm, 60 cm and 1.2 m. They found that bodies buried close to the surface (30 cm – 60 cm) decomposed much faster than those in deeper graves (1.2 m). The rate of decomposition of buried bodies is estimated to be eight times slower than that of bodies located on the surface. There are two major factors possibly responsible for this phenomenon.

Firstly, the soil restricts the access by carrion insects as well as scavengers. Most insects could not colonize a body buried deeper than approximately 30 cm. Bodies buried closer to the surface (less than 30 cm deep) gave off decomposition odours that easily penetrated the soil. These odours attracted scavengers and insects to the site of burial. The carrion insects gained access to the body by migrating through the cracks and crevices made in the soil during bloating while the scavengers dug up and exposed parts of the body to feed on, resulting in an increase in the rate of decomposition (Rodriguez and Bass, 1985; Rodriguez, 1997; Turner and Wiltshire, 1999).

Secondly the soil itself acts as a barrier against solar radiation and thus also against high temperatures as well as temperature fluctuations. Soil temperature decreases as the depth increases and the rate of decomposition will therefore be reduced due to slower cooling of the body right after burial as well as the thermal stabilization of the soil (Rodriguez, 1997). According to Rodriguez and Bass (1985) thermal stabilization normally occurs at more than two feet (about 60 cm) of depth, while at depths of less than a foot (30 cm) temperatures are close to the ambient temperature. Additionally, most seasonal temperature fluctuations occur at depths of more than two feet while daily temperature fluctuations occur at less than one foot. Burials of four or more feet (120 cm) usually maintain temperatures that are not only lower but also more stable than shallower burials (Rodriguez, 1997).

Another aspect of the soil environment that affects the rate of decomposition is the soil composition i.e., the moisture level and presence of soil organisms. The degree to which these two factors influence the rate of decomposition is also dependant on the burial depth since the levels of moisture and soil organisms differ at the various depths (Rodriguez, 1997; Turner and Wiltshire, 1999).

Bodies buried in soil with a high moisture content, or clay soil, often have reduced rates of decomposition due to extensive adipocere formation. Clay soil is also known to absorb and bind to certain enzymes (Skujins, 1967) and is less permeable and thus poorly drained. Turner and Wiltshire (1999) assume that the microbial enzymes or breakdown products of decomposition may be inactive due to this binding effect, thereby delaying decomposition. This could also reduce odour and/or release and result in the absence of animal scavenging. Typically, soils at greater burial depths have higher moisture content due to the reduced degree of evaporation and closer proximity to the underground water tables. A body associated with clayish soil or the moist soil of deeper burials will thus exhibit a reduced rate of decomposition (Rodriguez, 1997).

Soil fauna and flora also have an effect on the rate of decomposition of a buried body. Plant roots often grow towards the nutrient-rich decomposition fluids surrounding the body (Rodriguez, 1997). These roots often aid in the decomposition of a body by penetrating and adhering to the clothing and skeletal remains, causing large amounts of degradation. The skeletal remains often exhibit etching of the cortex or penetration of the bony trabeculae and foramina by plant roots (Willey and Heilman, 1987; Hall, 1997; Rodriguez, 1997). Like the roots, insects and bacteria found in soil also contribute to the degradation of clothing, soft tissue and bones. The soil organisms and plants are more abundant in the shallower, nutrient-rich, upper soil and contribute to the increased rate of decomposition associated with burials in a shallow grave (Rodriguez, 1997).

Therefore, bodies buried at depths of 30 cm to 60 cm become skeletonized within a few months to a year, while bodies buried at 90 cm to 1.2 m may take several years to reach the same level of decomposition (Mann *et al*, 1990; Rodriguez, 1997).

2.2.4.3.2 Submersion

Like burial, submersion of a body in an aquatic environment delays the rate of decomposition to the extent that it may be roughly half of that of a body exposed to air (Rodriguez, 1997). Bodies found in water masses often follow a specific sequence of events. The body proceeds to sink in the water as most of the air is expelled from the lungs. As active decomposition takes place, gas collects in the gastrointestinal tract and causes the body to float to the surface. Finally the body sinks again due to purging of putrefactive gasses (Boyle *et al.*, 1997; Rodriguez, 1997). There are different aspects to aquatic environment that impede decomposition, including the temperature of the water, the depth of the water, aquatic insects/scavengers, bacterial content and salinity (Boyle *et al.*, 1997; Rodriguez, 1997; Sorg *et al.*, 1997).

Bodies submerged in warmer waters decompose faster and will resurface earlier than bodies located in cold or near-freezing waters. Also, the water temperature usually decreases with depth, slowing decomposition further and also delaying resurfacing of the bodies (Boyle *et al.*, 1997; Rodriguez, 1997).

The salinity of the water not only influences the rate of decomposition but also causes changes to the body. In general, bodies submerged in salt water sources decompose at a slower rate than those in fresh water. This is due to a reduction in bacterial action since the high salt concentration retards bacterial growth (Boyle *et al.*, 1997; Rodriguez, 1997). Conversely, a high bacterial content and large amount of organic waste in fresh water causes the rate of decomposition to accelerate (Rodriguez, 1997).

Aquatic insects and scavengers greatly increase the rate of decomposition by feeding on the soft tissues of the body, resulting in loss of buoyancy and disarticulation (Boyle *et al.*, 1997; Rodriguez, 1997). Many authors (Rathbun and Rathbun, 1984; Spitz, 1993; Boyle *et al.*, 1997; Rodriguez, 1997; Sorg *et al.*, 1997) have named a variety of scavengers (i.e., crabs, fish, and turtles) that may cause disarticulation and other modifications of a decomposing body or skeletal remains.

A common modification that takes place is the formation of adipocere. Numerous cases of extensive adipocere formation in aquatic environments have been documented (Mant and Furbank, 1957; Mant, 1960; Cotton *et al.*, 1987; Dix, 1987; O'Brien, 1994, Rodriguez, 1997). The formation of adipocere generally takes place within a limited temperature range of approximately 21°C (Tomita, 1975) to 45˚C (Corry, 1978). At these temperatures the bacterium *Clostridium perfringens (welchii),* involved in the formation of adipocere, exhibits optimum growth (Payne and King, 1972; Tomita, 1975; Corry, 1978; Cotton *et al.*, 1987). If the temperatures are higher or lower than the above temperatures, no adipocere forms since high temperatures cause the tissues to liquefy and low, or freezing, temperatures slow or arrest decomposition (O'Brien, 1997). Clearly the temperature of the water in which the body is submerged has a major influence on the decomposition thereof.

2.2.4.3.3 Surface the body is placed upon

Not much is known about the influence of the type of surface a body is placed on has on the rate of decomposition. Mann *et al.* (1990) observed that bodies placed on concrete surfaces usually have a decreased rate of decomposition, though no provable reason for this phenomenon could be provided. Possible reasons for the altered rate of decomposition include the retention of moisture of certain surfaces as well as the influence of specific components of the surface on the various processes involved in decomposition.

2.2.4.3.4 Sun exposure

Shean and colleagues (1993) observed that carcasses placed in sun-exposed areas decomposed at a faster rate than those in shaded areas. Recordings of the ambient air temperatures showed that the daily temperatures are higher in sun exposed areas as opposed to shaded areas while evening temperatures are lower at the exposed site than in the shaded areas. This indicates that exposed regions have more pronounced maximum and minimum temperatures which may have a significant effect on the decomposition rate. The difference between the ambient air temperature and the maggot mass temperatures is much greater at the sun exposed areas than the shaded areas, thus indicating a larger degree of maggot growth and activity. This may lead to a more rapid rate of decomposition in the sun-exposed carcasses (Shean *et al.*, 1993; Wells and Lamotte, 2001). However, the effect on the rate of decomposition may have been influenced by the smaller size of the sun exposed carcass while Hewadikaram and Goff (1991) observed greater thermal rises and more rapid decomposition in a larger carcass. Another factor that may have influenced the decomposition rate is the difference in the amount of moisture at the two sites (Shean *et al.*, 1993).

The sample size in this study was small and may not be an accurate representation of the effect of sun exposure on the rate of decomposition.

Galloway and associates (1989) observed that for sun exposure to be advantageous to decomposition, a certain amount of solar radiation is necessary under different circumstances. As already mentioned, certain insects can only lay eggs if an appropriate amount of sun exposure or shade is available to either provide heat during colder seasons or shade during hot temperatures to ensure maggot viability, respectively. Researchers have also observed that egg-laying and insect colonization decreased during cloudy days (Galloway *et al.*, 1989; Campobasso *et al.*, 2001). Galloway and colleagues noted that during winter, maggot activity only took place during the day since the solar radiation from the sun aided development (Galloway *et al.*, 1989; Galloway, 1997).

Furthermore, scavenger activity is also influenced by sun exposure. Dillon and Anderson (1995) observed that scavenger activity is low in sunny habitats resulting in nocturnal consumption of soft tissues while insects such as blow flies are diurnal (Anderson, 2001).

Sun exposure often has a more profound effect on the body after the decomposition of the soft tissues, i.e. during post-skeletonization. Bleaching and increased brittleness of skeletal elements are observed in areas of sun exposure (Ubelaker, 1989). Sun exposure thus increases the rate at which bone weathering takes place, which can result in larger PMI estimates due to an “older” appearance of skeletal elements (Lyman and Fox, 1997; Janjua and Rogers, 2008).

2.2.4.4 Carnivore and scavenger activity

Carnivores and scavengers have such a considerable influence on the rate of decomposition that many researchers include observations of their effects in studies. Various types of mammals can be found feeding off a carcass but the most commonly recorded are canids, i.e., dogs and coyotes (Haglund *et al.*, 1988, 1989; Galloway *et al.*, 1989; Mann *et al.*, 1990; Galloway, 1997; Haglund, 1997a; Rodriguez, 1997), rodents (Haglund *et al.*, 1988, 1989; Haglund, 1997b; Rossi *et al.*, 1994), birds (Bass, 1997; Rodriguez, 1997; France *et al.*, 1997; Sorg *et al.* 1997), bears (Galloway *et al.*, 1989; Merbs, 1997), mountain lions (Murad, 1997) and salt water predators (sharks, crustaceans, etc.) (Sorg et al. 1997).

Carnivores and scavengers, such as dogs and coyotes, have a larger influence on decomposition rates than smaller mammals (Haglund, 1997a). Their scavenging is commonly reported in cases involving carcasses in terrestrial environments (Bass, 1984; Mann *et al.*, 1990; Galloway *et al.*, 1989; Haglund, 1991, 1997a; Haglund *et al.*, 1988, 1989; Rossi *et al.*, 1994; Galloway, 1997). Carnivores accelerate decomposition by (1) disarticulation and consumption of the soft tissues; (2) scattering of remains; and finally (3) damaging and/or consumption of the bony elements (Mann *et al.*, 1990; Galloway, 1997; Haglund, 1997a).

Disarticulation and consumption of the soft tissues of the body can rapidly result in partial skeletonization by creating access points for insects, exposing the bones to other types of taphonomic processes such as weathering, and reducing the body into smaller units that are easier to scatter and consume (Haglund, 1997a). According to various researchers (Hill, 1979; Haynes, 1980, 1982; Haglund, 1991), disarticulation by canids can be grouped into stages since the whole process takes place in a fairly consistent sequence. Haglund (1991) described the stages of canid-scavenged disarticulation from 53 canid-scavenged human remain cases using the proposed model first described by Hill (1979) and Haynes (1980, 1982). Table 2.2 summarizes the sequence and stages of soft tissue consumption and disarticulation as described by Haglund (1989; 1997a).

Table 2.2. Sequence and stages of soft tissue consumption, bone damage and disarticulation by canids as observed by Haglund (1989; 1997a).

Stage	Soft tissue consumption and bone damage	Disarticulation
0	Consumption of the skin and muscle of face; removal of neck organs; slight damage to the orbital bones; damage to the nasal aperture; and consumption of the hyoid	No removal of body units
1	Evisceration; destruction to skeletal elements of the vertebral thorax; consumption of muscle from the thorax, pelvis, and thighs.	Disarticulation and/or scattering of one or both upper extremities
2	Consumption of remaining soft tissues of the lower extremities	Full or partial removal of lower extremities
3	Bone damage at proximal and distal segments of long bones	Near complete disarticulation with the exception of segments of the vertebral column; increased amount of scattering
4	Extensive gnawing of skeletal elements	Complete disarticulation with widespread scattering

Although the sequence of canid-assisted scavenging remains relatively constant, certain modifications can occur that result in an uneven consumption of soft tissue or random disarticulation (Haglund, 1997a). For example, when portions of the body are sheltered, wrapped in clothing, submersed, buried or covered with snow (Haglund, 1997a; Rodriguez, 1997) the above described pattern may vary.

The amount of damage caused by smaller mammals is not as distinct as that of larger scavengers, but is important nonetheless. These scavengers such as rodents, e.g., rats, mice and porcupines, often cause damage to the skeletal elements by gnawing, but soft tissue damage during the early stages of decomposition is not uncommon (Knight, 1991; Haglund, 1992, 1997b; Patel and Path, 1994, Galloway, 1997).

Birds are also commonly observed on decomposing bodies. However, it appears that small birds feed on insects and insect larva instead of on the decayed flesh, while larger birds such as crows and vultures typically feed on the corpse itself during the more advanced stages of decomposition (Bass, 1997; Rodriguez, 1997; Reeves, 2009). Moreover, birds have also be seen feeding on the exposed remains of a partially submerged body (Boyle *et al.*, 1997).

Animal scavenging is not restricted to terrestrial environments; there are also many aquatic animals involved in scavenging of partial or fully submerged bodies. Examples are (1) various fish including sharks, (2) crustaceans e.g., crabs, shrimp, lobsters; (3) mollusks e.g., snails, chitons, cephalopds; and (4) echinoderms e.g., sea stars, sea urchins (Sorg *et al.*, 1997).

An important factor to consider when studying the influence of carnivore and scavenger activity on the rate of decomposition is the time needed for the scavenging to occur. Haglund and colleagues (1989) reported that carnivore activity appeared to begin early during decomposition, while Galloway *et al.* (1989) recorded activity during the advanced stages of decomposition to skeletonization/mummification. The reason for this variation in scavenging time may be due to differences between feral dog and coyote concentration in the Southwest compared to the Northwest of the United States (Galloway, 1997). Differences in the scavenging time and degree of scavenging between regions are influenced by the type of scavenger, as differences in the types and number of specific scavengers varies between regions and results in differences in the degree of scavenging and the scavenging time (Galloway *et al.*, 1989; Galloway, 1997). For example, coyotes and bears are major contributors to animal scavenging in North America, while a large amount of scavenging is caused by jackals and large dogs in South Africa (Pickering *et al.*, 2004). Human population density also affects scavenging degree and time as it is minimal in regions with higher population densities due to smaller animal groups or fewer animals as well as the increased likelihood of discovering the body (Haglund *et al.*, 1989; Haglund, 1997a). Another factor is seasonality, such as hunger and/or the seasonal availability of food sources affects the behaviour of the scavengers, the type of ground cover i.e., snow or leaves, and the amount of clothing the body is covered with, which can restrict scavenging (Haglund, 1997a). Additionally, the condition of the remains, for instance, adipocere formation may deter animal scavenging, whereas fresh remains may attract some scavengers, while advanced odours of putrefaction may be necessary for scavenging to take place by other animals (Galloway *et al.*, 1989; Galloway, 1997, Haglund, 1997a). Finally, accessibility to the remains is key, for instance bodies located in enclosed environments do not exhibit scavenger activities. In addition, the position of the body may limit access of certain parts to smaller scavengers (Haglund, 1997a).

2.2.4.5 Physical appearance of the body

2.2.4.5.1 Trauma

The presence of trauma i.e., blunt force trauma, sharp force trauma and gunshot wounds, generally results in an increase in the rate of decomposition (Galloway *et al.*, 1989; Mann *et al.*, 1990; Rodriguez, 1997; Campobasso *et al.*, 2001). Usually insects prefer to lay eggs in the natural bodily orifices or adjacent surfaces that are moist, creased enough to provide some protection to the eggs and with enough oxygen to ensure the viability of the offspring (Galloway *et al.*, 1989; Haskell *et al.*, 1997; Campobasso *et al.*, 2001). Penetrating wounds or gross trauma attract and offer additional access points for various insects to deposit their eggs, since the wounds are moist and maintain contact with air (Galloway *et al.*, 1989; Mann *et al.*, 1990). This often results in an increased rate of decomposition around the wound site and thus modifications in the decomposition sequence. Rodriguez (1997) mentions irregular decomposition of the body of an adult female suspected of and later confirmed by skeletal analysis to have been stabbed in the chest. Extensive maggot infestation with advanced states of decomposition of the soft tissue was observed in the regions of the chest and palms of both hands. In contrast, the rest of the body exhibited a lesser degree of decomposition. Rodriguez concluded that the premature decomposition in these regions were due to the presence of wounds that provided an access point for bacteria and insects (Rodriguez, 1997). It is not only insects that take advantage of the presence of wounds on a body; many scavengers are attracted by open wounds. This causes scavenging to take place earlier than normal and results in a greater degree of soft tissue damage (Haglund, 1997a). However, a recent study by Cross and Simmons (2010) found that there was no difference in the rate of decomposition between two groups of pigs (penetrative trauma vs. non trauma) since Diptera prefer the natural orifices to trauma sites although the trauma sites still provide additional access points to the soft tissues for larvae.

2.2.4.5.2 Body size, weight and composition

A few studies (e.g., Mann *et al.*, 1990; Hewadikaram and Goff, 1991; Campobasso *et al.*, 2001) have referred to the effect of the size, weight and constitution of the body on the rate of decomposition. Hewadikaram and Goff (1991) observed, using a 15.1 kg and an 8.4 kg carcass, that the pattern of decomposition remains similar but that the rate of decomposition is influenced. The larger carcass decomposed at a faster rate during the decay and post-decay stages while the difference in the rate of decomposition during the earlier and later stages was less pronounced. This phenomenon is possibly due to the greater number of adult flies, and thus maggots, observed on the larger carcass during the decay stage which resulted in a more rapid removal of soft tissue. The outcome of this study supported the observations of Denno and Cothram (1975) which indicated that the size of the carcass can be directly related to the density of the fly population.

The constitution of the body also has an influence on the decomposition rate because obese bodies lose a greater deal of body mass due to liquefaction of the body fats (Mann *et al.*, 1990; Campobasso *et al.*, 2001). This rapid loss of body fat is probably caused by the greater extent of bacterial dissemination and development that favours the large amount of liquid in these tissues (Campobasso *et al.*, 2001).

2.2.4.5.3 Clothing and other coverings

The type and amount of clothing or covering on a body can influence the rate of decomposition in two ways. First, a small amount of clothing or other covering can protect the body from direct sunlight, snow and rain and thereby provide shelter for developing maggots, causing an increase in the rate of decomposition (Mann *et al.*, 1990; Campobasso *et al.*, 2001). Secondly, heavy clothing or coverings such as plastic slows down post-mortem body cooling and often protects the body against insect access or animal scavenging, thus delaying decomposition (Haglund, 1997; Campobasso *et al.*, 2001). Galloway and colleagues (1989) found this phenomenon occurring in advanced stages of decomposition. An experiment conducted by Rodriguez and Bass (1986) clearly demonstrates the effect of impermeable materials on the decomposition process. Specific regions of two bodies were wrapped in plastic and the bodies were buried. Upon excavation several months later, these body parts exhibited marked preservation in contrast to the rest of the body. They concluded that the build-up of the bacterial by-products resulted in suppression of the bacterial activity, without which decomposition is retarded (Rodriguez and Bass, 1986; Rodriguez, 1997).

2.3 The use of ADD to estimate the PMI based on the morphology of decomposition

Forensic entomology was first applied in court in 1980 and since then has become extremely important in medical-criminal investigations (Bergeret, 1855; Hall, 2001). Numerous studies have been done on the succession patterns of insects on a corpse (Rodriguez and Bass, 1983, 1985; Early and Goff, 1986; Catts and Haskell, 1990; Anderson and VanLaerhoven, 1996; Anderson *et al.*, 2001; Carvalho *et al.*. 2004; Grassberger and Frank, 2004), however with the rise in the importance of forensic entomology in medico-criminal investigations, more reliable data on rates of larval development and the intervals taken to reach these stages are required. This resulted in the use of thermal summation by forensic entomologists to estimate the rate of development of insects (Amendt *et al.*, 2004).

The method of thermal summation was first applied by botanists to measure or to predict the effect of temperature on plant growth (Baskerville and Emin, 1968). In 1972, Wiggelsworth discussed a number of different methods to relate the rate of development to temperature known as Accumulated Degree-Hours (ADH) or Accumulated Degree-Days (ADD). This method is based on the assumption that relations between the rate of development of an insect and the environmental temperature are linear in the mid-range of a sigmoid curve. Furthermore there is an upper and lower limit threshold below which development no longer takes place (Haskell *et al.*, 1997; Greenberg and Kunich, 2002). ADH or ADD are the units of energy/heat that are calculated to form the total amount of heat that is required between the upper and lower thresholds and is therefore the product of time and temperature between the thresholds for each day (Greenberg and Kunich, 2002; Amendt *et al.*, 2004). Thus by using the daily averages of the minimum and maximum temperatures, the accumulation of these heat energy units can be used to estimate the PMI.

In 2005, Megyesi and colleagues proposed that the Total Body Score (TBS) and Accumulated Degree Days (ADD) could be used to determine the post-mortem interval. The study made use of 68 human remains cases from a variety of settings. The bodies found outdoors were located in full sun, shaded areas and areas that received a mix of sun and shade. The bodies found indoors were located in houses, apartments and trailers. It was also noted whether the bodies were covered by clothing or whether they were nude. Furthermore, the sample consisted of individuals between the ages of 11 and 72 with a mean age at death of 32.3 years (SD=15.9). Only cases with PMI's of less than one year were used since little soft tissue is present beyond this period.

The state of decomposition was observed and scored. This scoring method was developed by first dividing decomposition into its four broad categories. These categories were then subdivided into stages describing the general appearance and characteristics of the remains. Each stage was assigned a point and since all the stages of decomposition do not apply equally to all parts of the body, three separate scoring strategies were used: one for the head and neck, one for the trunk and one for the limbs. The scores assigned to each region were then combined to produce the total body score (TBS) as seen in Figure 2.2.

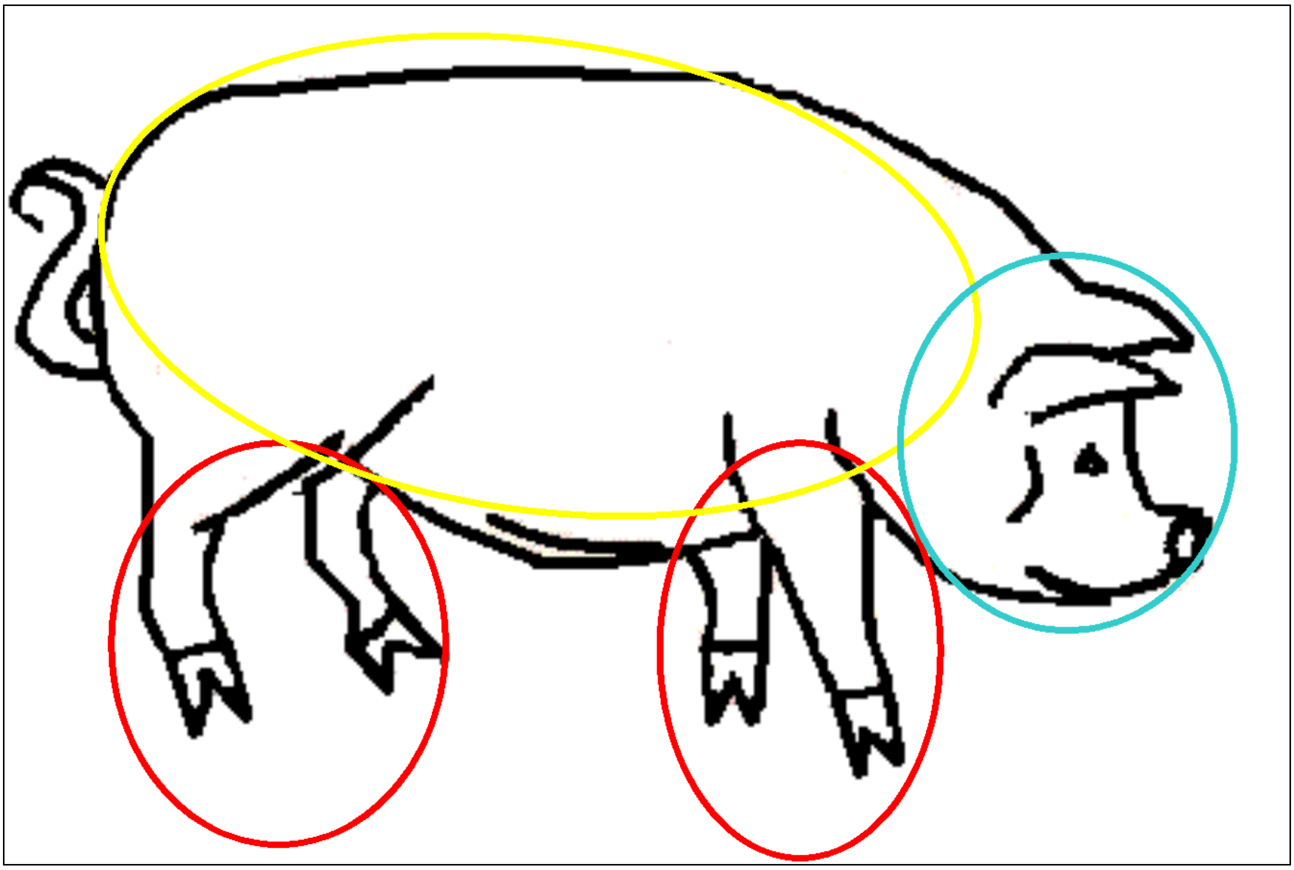

Figure 2.2. The scoring of the three anatomical regions to calculate the TBS (Blue = Head and neck, Yellow = Trunk, Red = Limbs).

Accumulated degree days were calculated by collecting temperature data for the post-mortem interval of each case from a National Weather Service Station. The temperature data were composed of daily averages i.e., the average of the maximum and minimum air temperatures. Temperatures below 0ºC were recorded as zero rather than negative values since it is accepted that decomposition does not take place at temperatures below freezing point.

Statistical analyses of the TBS of each individual in the sample, plotted against the known PMI's and then the ADD's, showed that decomposition or TBS first increases rapidly then levels off in a loglinear fashion. Transforming the variables through loglinear regression caused the curve to "straighten" and led to the development of a simple formula that can be used to calculate the ADD:

$$\mathbf{ADD = 10^{(0.002*TBS*TBS+1.81)} \pm 388.16}$$

After the ADD has been determined, one would determine PMI by obtaining the average daily temperatures and start counting backwards from the day of discovery until the accumulated sum equals the estimated ADD. Confidence intervals of roughly 95% can be calculated, which seems to make this method accurate and reliable. However, the method can only be used when examining decomposed remains that are exposed to the outside environment. These formula developed should only be used on adult-sized remains and remains that have not been buried, submerged or burned.

To utilize this method when a body is discovered, the TBS is estimated using the descriptions developed by Galloway and associates (1989) and modified by Megyesi and colleagues (2005). As a first step, the **estimated** ADD is calculated by using the following formula:

$$ADD = 10(0.002*TBS^2 + 1.81) \pm 388.16$$

For example, if the TBS is 28, the accumulated degree days can be predicted as follows:

$$ADD = 10(0.002(28)^2 + 1.81) \pm 388.16$$

$$ADD = 10(3.378) \pm 388.16$$

$$ADD = 2387.81 \pm 388.16$$

Estimated ADD = 1999.65 days ºF to 2775.97 days ºF

The **actual** ADD value is calculated by collecting the average daily temperatures from the nearest weather station to the site until the **actual** ADD value is equal to the **estimated** ADD value plus/minus the standard error. Due to variations in the microclimates between the site of death and the weather station, a temperature correction factor may have to be used to compensate for this difference in cases where significant variation exists. This is done by collecting data from the site of death and then comparing it to the data collected from the weather station. If the two datasets differ considerably the average daily temperatures can then be adjusted accordingly.

Working backwards in time from the date of discovery of the body until the **actual** ADD value is equal to the **estimated** ADD value (2387± 388.16 in this example) represents the number of days since death or the PMI range (31 to 43 days if the average daily temperatures were approximately 65ºF). Since these methods have been developed in North America, the temperatures units have to be converted for the South African setting and thus the **estimated** PMI would be 31 to 43 days of approximately 18ºC weather.

Similar studies have been done by Schiel (2008) and Parsons (2009). These studies were longitudinal in nature and involved the use of pig models to study the proposed method of Megyesi *et al.* (2005). Schiel (2008) observed more accurate estimates for ADD, using the equations developed for 10 pigs in her longitudinal data set than for the quadratic equation developed by Megyesi *et al.* (2005) for the 66 forensic cases used in their study. Comparisons of the mean error between the equations of the two studies revealed that the inaccuracy value (SE: 167.75) for the estimated ADD equations of Schiel (2008) was less than that for the Megyesi *et al.* (2005) equations (SE: 178.88). Furthermore, Schiel (2008) indicated that seasonality did not have a major influence on the use of ADD to estimate the PMI.

Parsons (2009) made use of two pigs (one placed during the warmer period and another during the colder period) to study the decomposition patterns in West Central Montana, USA. Similar to Schiel (2008), this study was longitudinal in nature. Parsons (2009) observed that PMI estimations of their own dataset fell within the 80% confidence interval suggested by Megyesi *et al.* (2005) and the patterns of decomposition observed in her study indicated that ADD estimations become more accurate during the later stages of decay. However, she concluded that the ADD method can be used in regions with cold temperatures and low humidity. This supports the use of ADD to study decomposition and produce PMI estimation in various climatic regions.

2.4 Decomposition research in South Africa

Research focusing on the rate and macroscopic appearance of decomposition with the intention to use the results to estimate the post-mortem interval has not yet been done in South Africa. However, research has been conducted on the use of the life cycles of necrophage species to establish time since death. In 1980, André Prins from the South African Museum was the first to pursue studies into the rate of decomposition and its value in the forensic sciences (Prins, 1980; Williams and Villet, 2006). In 1992, TC van der Linde and members of the Department of Forensic Medicine at the University of the Free State in Bloemfontein established the Forensic Entomology Investigation Team of the University of the Orange Free State (Oranje Vrystaat; FEITUOVS) (Louw and van der Linde, 1993; Williams and Villet, 2006). Within this team, many different research topics have been studied and include types of insect carrion (Louw and van der Linde, 1993), development rates of maggots (Leopoldt and van der Linde, 1993; Stadler and van der Linde, 1995), as well as studies involving the succession of carrion on pig carcasses under varying circumstances (Williams and Villet, 2006). Furthermore, the Southern African Forensic Entomology Research (SAFER) laboratory was established at Rhodes University where it conducts various forensic entomological studies (van Wyk, 2005). In addition, Dr M Mansell from The U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS), Pretoria, became actively involved in several cases where he assisted the police with entomological assessments.

Chapter 3: Materials and Methods

3.1 Materials

3.1.1. Location of study

This study was conducted at the Forensic Anthropology Body Farm (FABF) on the Miertjie Le Roux Experimental Farm which belongs to the Faculty of Natural and Agricultural Sciences of the University of Pretoria. The farm is approximately 45 km from Pretoria on the N4 and is located at Kaalfontein 513 JR, District Cullinan in the Gauteng province.

The total size of the experimental farm is 570 hectares of which 150 hectares are dry land for maize production, 25 hectares dry land pastures and 396 hectares are natural sour veldt allocated for beef production with a 90 cow Bonsmara herd. A map (Figure 3.1) demonstrates the terrain and a satellite image (Figure 3.2) shows an aerial view of the FABF and the surrounding region where the enclosure is located (25º 47′ 20″ S; 28º 32′ 33″ E).

The location of the FABF was chosen in accordance with certain regulations established by the Department of Health such as that the enclosure had to be outside of a 2 km radius of any urban housing or workplace as well as at least 200 m away from any natural water supply. Ethical clearance was requested from the Animal Ethical Committee, Student Ethics Committee and the Environmental Biohazard Committee of the Faculty of Natural and Agricultural Sciences. The former two committees took note of the study; however since all animals had died of natural causes and no human specimens were involved approval from these governing bodies were not necessary. The latter committee, which is responsible for the safety of the environment where the study was performed, granted ethical approval after receiving conformation that the study fulfilled the criteria established by the Department of Health.

The enclosure was constructed in August 2008 by erecting a 50 m x 50 m, 1.2 m high chicken wire fence on a half hectare piece of veldt (Figures 3.2 and 3.3). The fencing allowed the interaction between the sample and the environmental conditions to be undisturbed while carnivore activity by large terrestrial animals was prevented. Some scavengers known to be found in the area include jackals, meerkats (suricates) and avian predators such as crows and cattle egrets (*Bubulcus ibis*). A gate was added to allow entry into the FABF for the transport of the pig carcasses.

The climate in South Africa ranges from sub-tropical regions on the eastern coastline to desert and semi-desert regions in the north west and Mediterranean winter rainfall regions in the southwestern coastal strip of the Western Cape (Benhin, 2006). However, the climate is largely dependant on the altitude of the area and proximity to the oceans and therefore may vary considerably from one region to the next (Benhin, 2006). The Miertjie Le Roux Experimental Farm is situated on the central Highveld plateau of South Africa and the climate consists of warm, wind-free summer days and mild winters, without snow and temperatures rarely below 0°C. Rainfall mainly occurs during the summer months with few winter showers. The humidity is low in most regions; however the high levels of humidity that are found on the Miertjie Le Roux farm are due to an underground river that runs through the region. The vegetation in this area consists mostly of sour veldt grasslands (Figure 3.4).

Figure 3.1. A road map indicating the location of the FABF (Black and red square) (Map of South Africa, 4 February, 2010 from http://maps.google.co.za)

Figure 3.2. Map of the terrain in the FABF region indicating the height above sea level (Map of South Africa, 4 February, 2010 from http://maps.google.co.za).

Figure 3.3. Satellite image of the FABF enclosure with the arrow indicating location of the FABF on Miertjie Le Roux Experimental Farm (Map of South Africa, 4 February, 2010 from http://maps.google.co.za).

Figure 3.4. The FABF enclosure. The arrow indicates the location of the gate to the enclosure. The black areas surrounding the FABF is the fire break (Map of South Africa, 4 February, 2010 from http://maps.google.co.za).

Figure 3.5. Grasslands in region of the enclosure (Taken 16 November 2009).

3.1.2. Study sample

The sample comprised of 30 pigs (*Sus scrofa)* that were received from a local farmer, Mr Thomas van Deventer. According to Mr van Deventer, he has 8000 pigs on his farm and approximately 2.5% of pigs died during the period of the study. Death was speculated to have been caused by Listeria (*Listeria monosytogenes*), *E. coli* (*Escherichia coli)* or a Clostridium (*Clostridium perfringens*) infection which is a common cause of deaths of pigs on commercial farms. The placement of pigs occurred within 12 hours after death. Only pigs that died of natural causes, had known dates of death and that showed no signs of peri-mortem trauma were included. No external wounds were present on the pigs, since it has been shown that there is an increase in the rate of insect colonization and activity at the site of the trauma, which in turn may result in accelerated rates of decomposition (Galloway *et al.*, 1989; Mann *et al.*, 1990; Haglund, 1997a; Rodriguez, 1997; Campobasso *et al.*, 2001).

Prior to placement, the pigs were weighed at the pig farm and then the height, length, thoracic width, pelvic width and belly height were measured according to the descriptions in Table 3.1 and as seen in Figure 3.6. These values are rough estimations since the positions of the pigs differed (i.e. pigs were laying in stretched out positions, slightly on their backs etc), but provided broad estimations of body size. The pigs used in this study were large and finishing pigs (21 to 90 kg) which are classified as Porkers (weights of 60 to 70 kg) and Baconers (weights of 70 to 90 kg) (Agricultural Research Council, 1993). All the pigs in the sample had to have a weight range of between 35 to 100 kg which was decided upon beforehand; this was done so as to reduce the effect of body size on the rate of decomposition and to ensure that a body size range was more or less similar to the range of adult humans.

Table 3.1. Descriptions for the measurements of the pigs.

Measurement	**Description**
Height (H)	The distance from the most dorsal portion of the back to the furthest point of the hind hoof
Length (L)	The maximum distance from the snout to the root of the tail
Width (W)	The maximum distance from the ground to the exposed lateral side in the thoracic region when the pig is laying on one side
Belly Height (BH)	The maximum distance from the ground to the exposed lateral side of the abdominal region measured perpendicular to the width

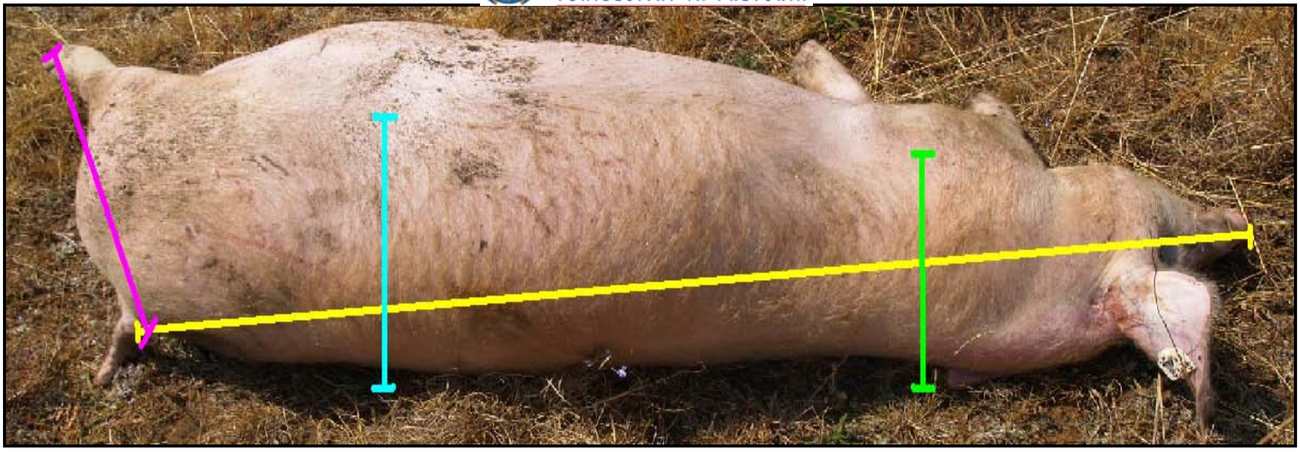

Figure 3.6. Figure demonstrating the measurements taken from each pig (Height = pink; Length = yellow; Width = green; Belly Height = Blue).

The pigs were placed approximately 10 m from each other to ensure that the insect colonization from one pig did not influence that of another (Shahid *et al.*, 2003). Each pig received a number upon arrival, and the date of death, date of placement, sex, weight, height, length, width and belly height for each pig was recorded.

3.2. Methods

3.2.1. Scoring macroscopic changes in decomposition

Data collection occurred three times a week until the late stages of advanced decomposition (i.e. almost completely skeletonized) when data were collected one day per week for each pig. The average daily temperatures (Appendix A, pp 93) and the stage of decomposition were scored and photographs were taken. During this period (13 August 2008 to 02 April 2009) an additional observer recorded the stage of decomposition of the pigs without influence from the primary investigator, and the information was kept separate until statistical analyses. This served to test the inter-observer repeatability of scoring.

The state of decomposition was assessed and scored, using the modified method by Megyesi *et al.* (2005) which is based on the original version by Galloway *et al*. (1989). The scoring guidelines were applied to different body regions since the manner and rate of decomposition has been shown to differ between these anatomical structures.

The three regions of the body, namely the head and neck, trunk and limbs, were scored. The descriptions of the stages are shown in Tables 3.2., 3.3. and 3.4. (Megyesi *et al.*, 2005). The allotted point value from each region was then added to reach the Total Body Score (TBS) which represents the overall stage of decomposition for each pig.

Table 3.2. Categories and stages of decomposition for the head and neck (Megeysi *et al*., 2005).

A. Fresh	
(1pt)	1. Fresh, no discolouration
B. Early decomposition	
(2pts)	1. Pink-white appearance with skin slippage and some hair loss
(3pts)	2. Gray to green discolouration: some flesh still relatively fresh
(4pts)	3. Discolouration and/or brownish shades particularly at edges, drying of nose, ears and lips
(5pts)	4. Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present
(6pts)	5. Brown to black discolouration of flesh
C. Advanced decomposition	
(7pts)	1. Caving in of the flesh and tissues of eyes and throat
(8pts)	2. Moist decomposition with bone exposure less than one half that of the area being scored
(9pts)	3. Mummification with bone exposure less than one half that of the area being scored
D. Skeletonization	
(10pts)	1. Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue
(11pts)	2. Bone exposure of more than half the area being scored with desiccated or mummified tissue
(12pts)	3. Bones largely dry, but retaining some grease
(13pts)	4. Dry bone

Table 3.3. Categories and stages of decomposition for the trunk (Megeysi *et al.*, 2005).

A. Fresh	
(1pt)	1. Fresh, no discolouration
B. Early decomposition	
(2pts)	1. Pink-white appearance with skin slippage and marbling present
(3pts)	2. Gray to green discolouration: some flesh relatively fresh
(4pts)	3. Bloating with green discoloration and purging of decompositional fluids
(5pts)	4. Post bloating following release of the abdominal gases, with discoloration changing from green to black
C. Advanced decomposition	
(6pts)	1. Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity
(7pts)	2. Moist decomposition with bone exposure less than one half that of the area being scored
(8pts)	3. Mummification with bone exposure of less than one half that of the area being scored
D. Skeletonization	
(9pts)	1. Bones with decomposed tissue, sometimes with body fluids and grease still present
(10pts)	2. Bones with desiccated or mummified tissue covering less than one half of the area being scored
(11pts)	3. Bones largely dry, but retaining some grease
(12pts)	4. Dry bone

Table 3.4. Categories and stages of decomposition for the limbs (Megeysi *et al.*, 2005).

A. Fresh	
(1pt)	1. Fresh, no discolouration
B. Early decomposition	
(2pts)	1. Pink-white appearance with skin slippage of hands and/or feet
(3pts)	2. Gray to green discolouration; marbling; some flesh still relatively fresh
(4pts)	3. Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities
(5pts)	4. Brown to black discolouration, skin having a leathery appearance
C. Advanced decomposition	
(6pts)	1. Moist decomposition with bone exposure less than one half that of the area being scored
(7pts)	2. Mummification with bone exposure of less than one half that of the area being scored
D. Skeletonization	
(8pts)	1. Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining
(9pts)	2. Bones largely dry, but retaining some grease
(10pts)	3. Dry bone

For example, as seen in Figure 3.7, if the head and neck exhibited caving in of the flesh, the trunk was in a stage of post bloat following the release of the abdominal gases with a black discolouration, and the limbs were discoloured with brownish shades particularly at the edges, scores of 7 (Blue), 5 (Yellow) and 4 (Red) were allocated. This resulted in a TBS value of 16.

Figure 3.7. An example of a pig in the advanced stage of decomposition (Blue = 7, Yellow = 5, Red = 4 for a combined score or TBS of 16)

3.2.2. Recording of ambient temperature and calculation of Accumulated Degree-Days

Temperature data was collected with an AZ8835 temperature and humidity data logger. Air temperature was taken every hour. All temperatures below 0ºC was recorded as zero since previous research (Micozzi, 1986; Catts and Haskell, 1990) have shown that freezing temperatures, below zero degrees Celsius, severely inhibit the biological processes that are required for decomposition to take place. For this study, zero degrees Celsius (˚C) was regarded as the base temperature.

Daily averages, i.e. the average of the maximum and minimum air temperature were calculated from the hourly temperature data recorded by the on site data logger and daily averages were also collected from the South African Weather Bureau (Appendix A, pp 93). The Accumulated Degree-Days were then calculated for each day by adding together the daily averages above 0˚C from the date of death until skeletonization was reached or data collection no longer took place. The rainfall during this period was also recorded with a rain meter located on site.

3.3. Statistical Analysis

3.3.1 Decomposition patterns

In order to assess the pattern of decomposition for the PMI and TBS and following from that the TBS and ADD, scatter plots were drawn up for the entire pig data set (Appendix B, pp 98).

In order to examine variation in seasonality and patterns of decomposition, the original data set which consisted of 627 observations (Appendix C, pp 106) was divided into winter and summer groups with 264 and 363 observations, respectively. Any pigs placed before 7 September 2009 (which is regarded as the beginning of spring in the Southern hemisphere) was characterized as the winter period, and all placed thereafter as the summer period. The reason for using the 7th of September is due to the increase in the average daily temperatures observed after this period (i.e. the increase in the number of days with temperature averages of 10-20ºC to 20-25ºC). Scatter plots were created to demonstrate the relationship between PMI and TBS and ADD, respectively.

3.3.2 Random-effects Maximum Likelihood regression

Due to the longitudinal nature of the data, Random-effects Maximum Likelihood regression was used to model ADD and PMI. Two models were derived: (1) ADD and PMI were respectively modeled against TBS, alone; (2) ADD and PMI were respectively modeled against TBS, together with season and with the interaction between TBS and season.

As both PMI and ADD values were expected to result in skewed distributions on the original scale, PMI and ADD were log transformed so as to be linearly related with TBS. These relationships were compared using their coefficients of determination (r^2). When multiplied by 100, the coefficients of determination expressed the percentage of the variation in logPMI and logADD that can be explained by the variation in TBS.

Models were reported on the original scale and for all possible combinations of the TBS predicted values of ADD and PMI were tabulated along with 95% confidence intervals. In other words, the formulated equations were used to produce a forecast of ADD and PMI for each TBS value including the standard error with the lower and upper limit forecast at a 95% confidence interval.

3.3.3 Inter-observer repeatability

Inter-class correlation was performed as a means to determine the repeatability of the proposed method of scoring the decomposition process. Inter-observer error was completed by an external individual scoring decomposition for the head and neck, trunk, limbs and the resulting TBS for the first ten pigs in the sample on the same day as the primary observer (Appendix D, pp 128).

If the coefficient of correlation is 1, a perfect or complete correlation exists, values of between 0.75 and 0.99 indicate a high degree of correlation, 0.5 to 0.74 indicates a moderate degree of correlation while values of less than 0.49 indicate a low degree of correlation. If the correlation of the description scores is high (above 0.75) it shows that the degree of decomposition, as reflected by the TBS, can be consistently repeated (Allan 1982).

Chapter 4: Results

4.1 Pig sample

Pigs were numbered according to the sequence of their arrival at the farm. The pigs carcasses were separated at least 10 m from each other, so as to minimize the effect of insect migration (Catts and Haskell, 1990; Early and Goff, 1986; Anderson and VanLaerhoven, 1996; Anderson *et al.*, 2001). This placement of the pig carcasses can be seen in Figure 4.1, the first pig to be placed was 001 and the last 030.

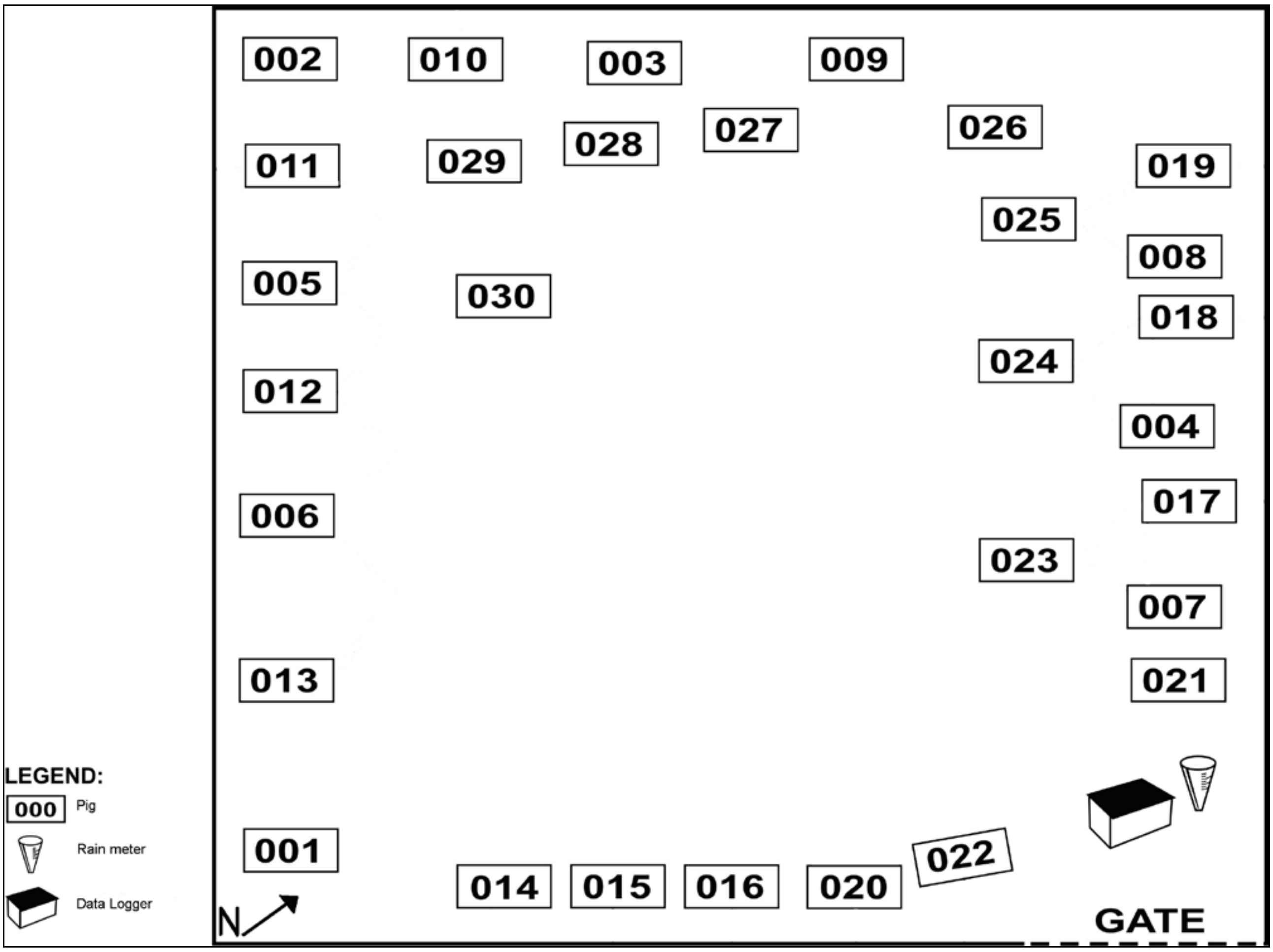

Figure 4.1. Location of pigs on the Forensic Anthropological Body Farm (FABF).

Body weight of the pigs ranged from a minimum of 38 kg to a maximum of 91 kg with the average weight being 71 kg (Tables 4.1 and 4.2). The size of the pigs was widely distributed, which resulted in pigs with different surface to weight ratios.

Table 4.1. Summary of the age at death, weight and metric dimensions of the sample (**estimation*)

Pig	Date of death/ placement	Sex	Weight (kg)	Height (cm)	Length (cm)	Width (cm)	Belly height (cm)
001	13/08/2008	Male	82	74	131	23	38
002	19/08/2008	Female	75	68	130	28	34
003	20/08/2008	Male	60	51	109	33	37
004	20/08/2008	Female	55	56	118	21	21
005	25/08/2008	Female	63	64	133	22	21
006	29/08/2008	Female	83	82	134	24	36
007	29/08/2008	Male	38	52	102	24	27
008	02/09/2008	Male	68	55	121	26	32
009	25/09/2008	Male	80	51	132	29	39
010	10/10/2008	Male	80*	57	152	28	36
011	13/10/2008	Female	59	45	128	26	37
012	16/10/2008	Male	85	38	143	29	32
013	16/10/2008	Female	80*	50*	130*	30*	40*
014	24/10/2008	Male	74	62	115	25	30
015	27/10/2008	Male	80*	80	148	26	32
016	27/10/2008	Male	65*	63	136	30	33
017	14/11/2008	Female	75*	70*	130*	25*	30*
018	14/11/2008	Female	65*	61	131	29	32
019	17/11/2008	Male	80*	50*	130*	30*	40*
020	24/11/2008	Male	65*	45*	125*	25*	35*
021	09/02/2009	Male	65*	53	137	26	31
022	09/02/2009	Male	70*	46	138	27	30
023	10/02/2009	Female	75*	50*	140*	30*	40*
024	10/02/2009	Female	75*	50*	140*	30*	40*
025	12/02/2009	Male	85*	67	149	28	39
026	12/02/2009	Male	68	54	144	27	34
027	23/02/2009	Female	70*	52	113	30	40
028	23/02/2009	Male	91	68	133	43	48
029	23/02/2009	Female	89	60	120	32	38
030	23/02/2009	Male	80*	55	130	39	42

Table 4.2. Minimum, maximum and averages of the pig weights and measurements.

Measurement	Weight (kg)	Height (cm)	Length (cm)	Width (cm)	Belly height (cm)
Minimum	38	38	102	21	21
Maximum	91	82	152	43	48
Average	71.3	58.9	130.3	28.1	34.1

4.2 Decomposition patterns of individual pigs

4.2.1 Complete/Combined pig data

To demonstrate the progression of decomposition, TBS and ADD were plotted against PMI (Figures 4.2 and 4.3, respectively). Fresh and early decomposition occurred rapidly with TBS values of 15 to 18 observed within 25 days after placement. In the later stages of decomposition, the pattern became highly variable (TBS values greater than 17). In Figures 4.2 and 4.3, both decomposition patterns followed a curvilinear pattern. However, these patterns are not identical due to the fact that a day is expressed as a unit of hours for PMI and a unit of temperature for ADD. While a day is fixed at 24 hours, the fluctuation of temperature within that period of time is not fixed and can vary within a week, within a season as well as between seasons. Therefore, the greater amount of variation in the later stages of decomposition may be due to pigs having been placed during different seasons, either winter or summer. In order to investigate time of placement and differences in temperature fluctuations with season, the sample was divided into winter (13 August 2008 to 6 September 2008) and summer (7 September to 23 February 2009) groups.

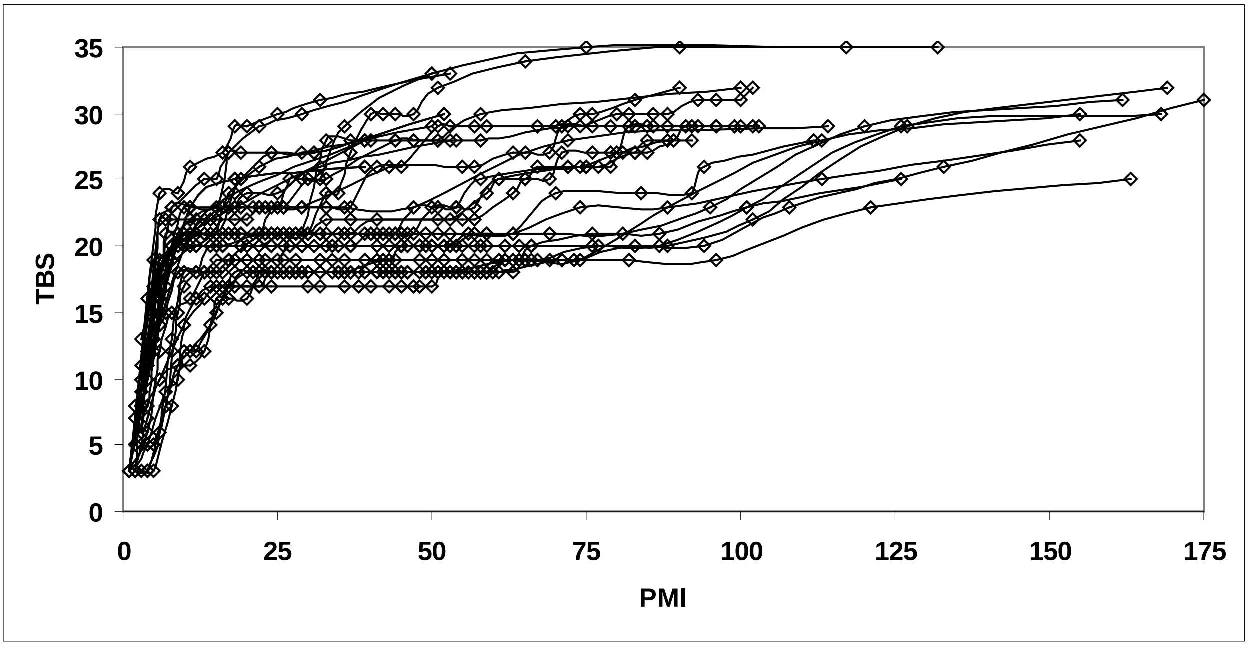

Figure 4.2. Scatter plot of TBS vs. PMI for each pig in the sample (N = 30).

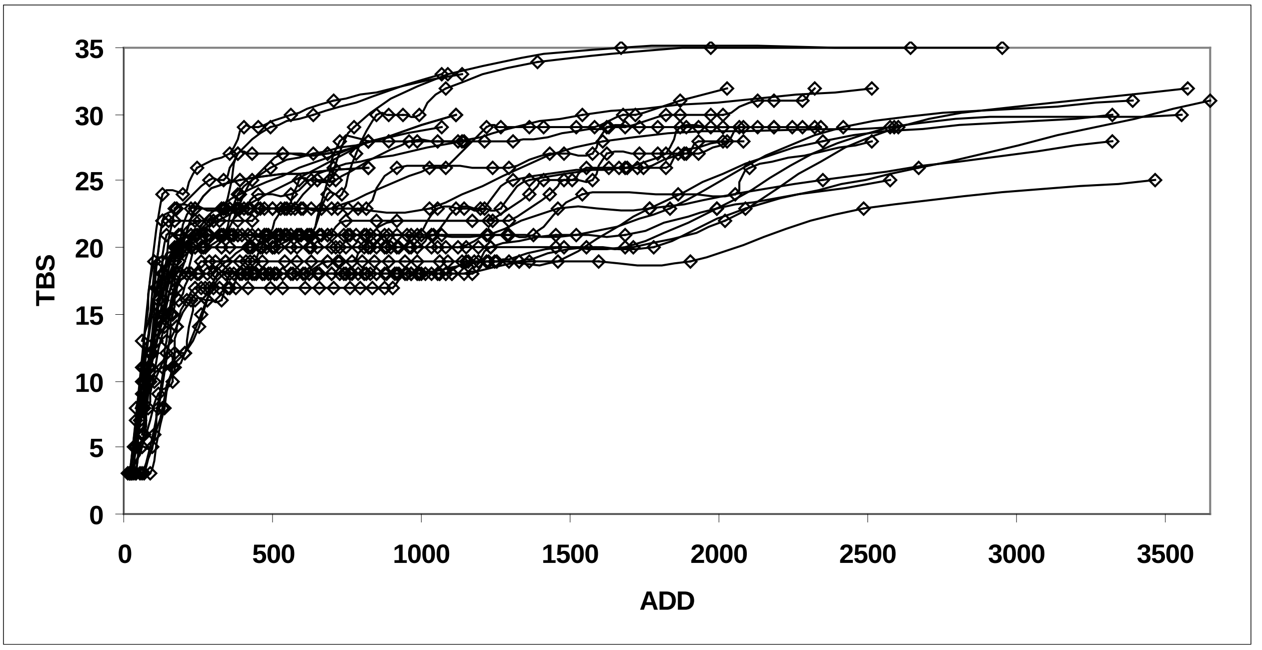

Figure 4.3. Scatter plot of ADD vs. TBS for each pig in the sample (N = 30).

4.2.2. Winter sample (date of placement: 13 August 2008 to 6 September 2008)

Eight out of the total of 30 pigs were included in the winter sample. Scatter plots of TBS vs. PMI (Figure 4.4) for all winter pigs produced a distinct decomposition pattern. (Individual decomposition patterns for winter are presented in Appendix B1 (pp 98).

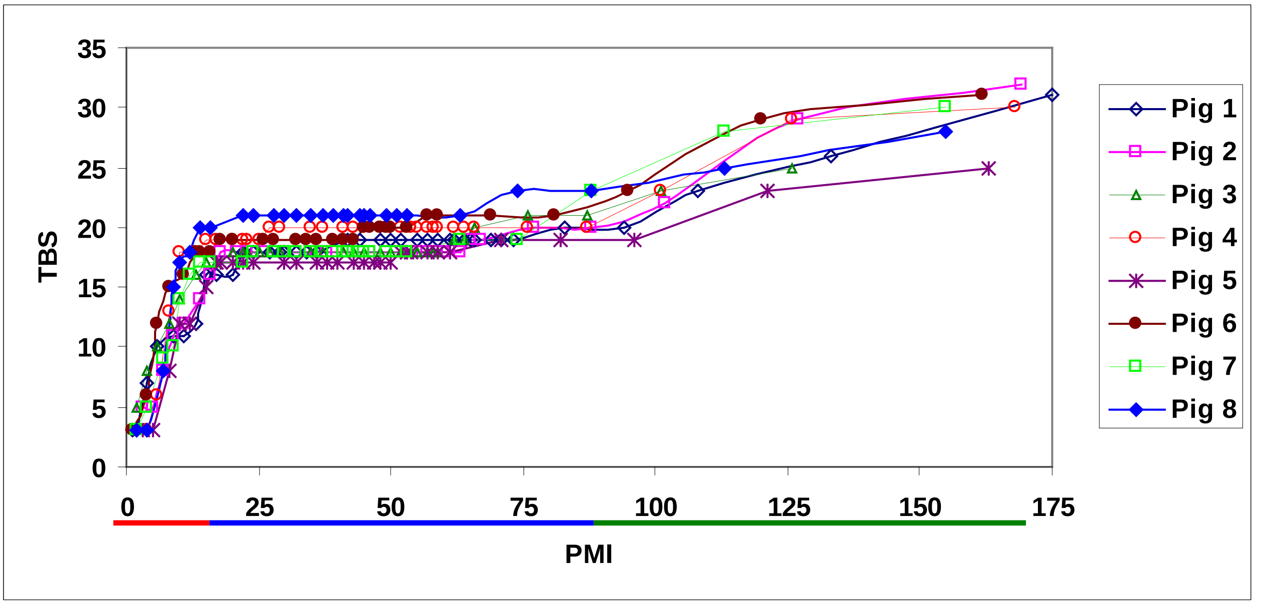

Figure 4.4. Scatter plots of TBS vs. PMI (in calendar days) for the winter pigs (n = 8).

In all specimens, the pattern of decomposition followed a sigmoid curve. The initial or early stages of decomposition (TBS scores of less than 16) occurred rapidly between 0 and 20 days (red line in Figure 4.4). The progression of decomposition then leveled off and little or no observable changes were found between 20 and 90 days after placement (blue line in Figure 4.4). During this period, no rainfall occurred, the tissues became desiccated and maggot activity was no longer observed (see Figure 4.5a). In October, approximately 56 mm of summer rainfall was recorded, which increased to as high as 160 mm in the month of December. Rainfall led to the re-moistening of desiccated tissues and the reuse of the corpse by insects. In turn, this caused the re-activation of decomposition which led to the eventual skeletonization of the remains (green line in Figure 4.4, and illustrated in Figures 4.5b and c).

a.)  b.) 

c.) 

Figure 4.5. Stages of advanced decomposition of a winter pig prior to rainfall at a PMI of 37 days (a); after the first rainfall during October at a PMI of 66 days (b) and after the November/December rainfall at a PMI of 126 days (c).

When ADD was plotted against TBS for all winter pigs, the decomposition pattern observed was similar to that found when between PMI and TBS (Figure 4.6 and Appendix B.2, pp. 99). During this period of time, the rate of decomposition was clearly dependent on the ambient temperature over a specified time period (number of days); therefore, decomposition could be quantified and similarly expressed as either unit of days (PMI) and/or unit of degrees (ADD).

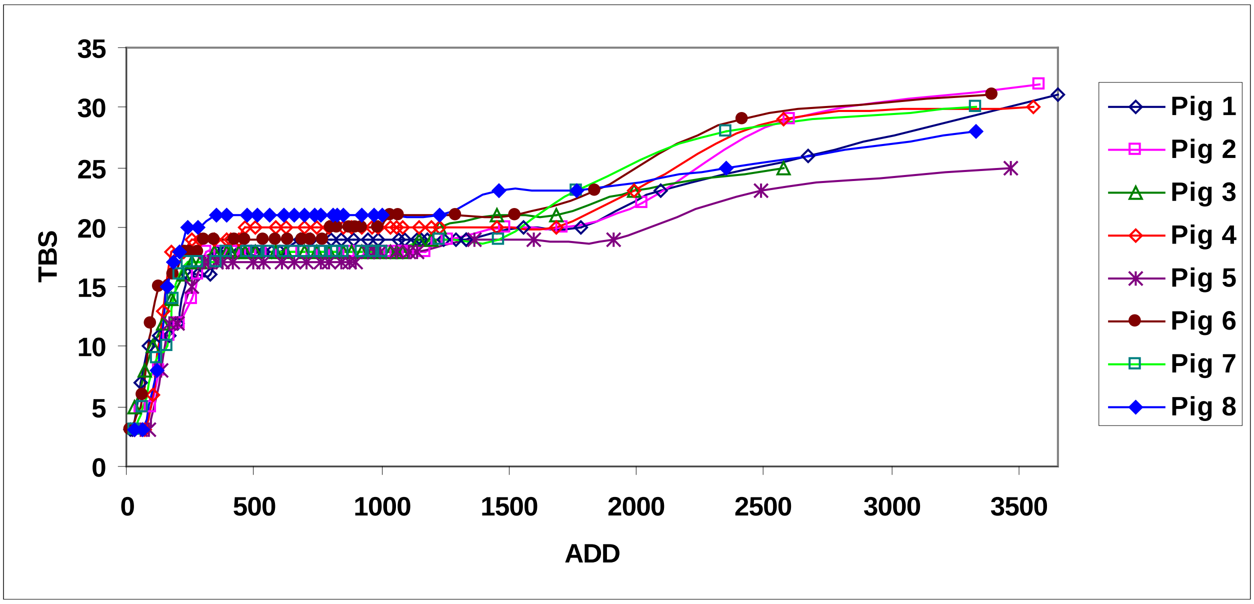

Figure 4.6. Scatter plot of TBS vs. ADD for the winter pigs (n = 8).

4.2.3. Summer (date of placement: 7 September 2008 to 23 February 2009) sample

The summer sample was comprised of 22 pigs. In this sample (Figure 4.7) decomposition was rapid from the early to advanced periods. After a TBS of 20 was reached (or 15-130 days after placement), the decomposition pattern became widely dispersed (red line in Figure 4.7). Possible reasons for this could be fluctuations in temperature between the early and later stages of summer as well as rainfall. Five of the pigs, whose placements were distributed over this summer period, were plotted separately so as to show differences in decomposition (see Figure 4.8; Pig 9 placed on 25 September 2008, Pig 15 placed on 27 October 2008, Pig 22 placed on 09 February 2009, Pig 26 placed on 12 February 2009 and Pig 30 placed on 23 February 2009; see Appendix B.3 for individual decomposition patterns of pigs 9 to 30, pp. 100).

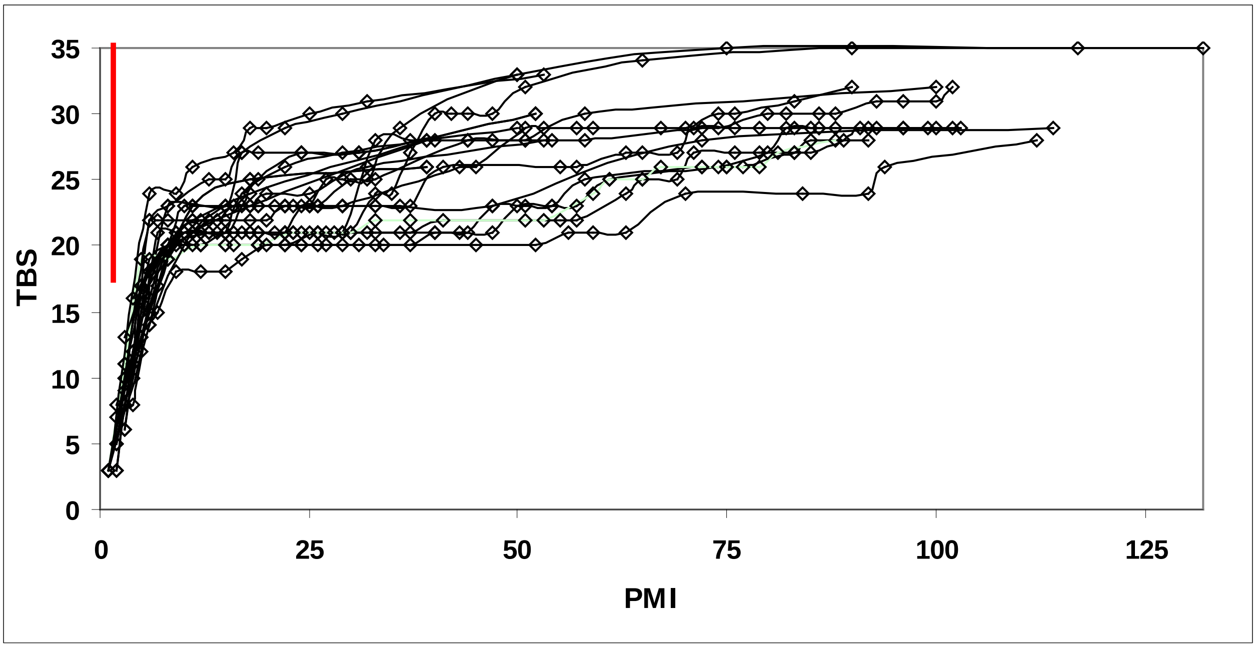

Figure 4.7. Scatter plot of PMI (in calendar days) vs. TBS for the summer pigs.

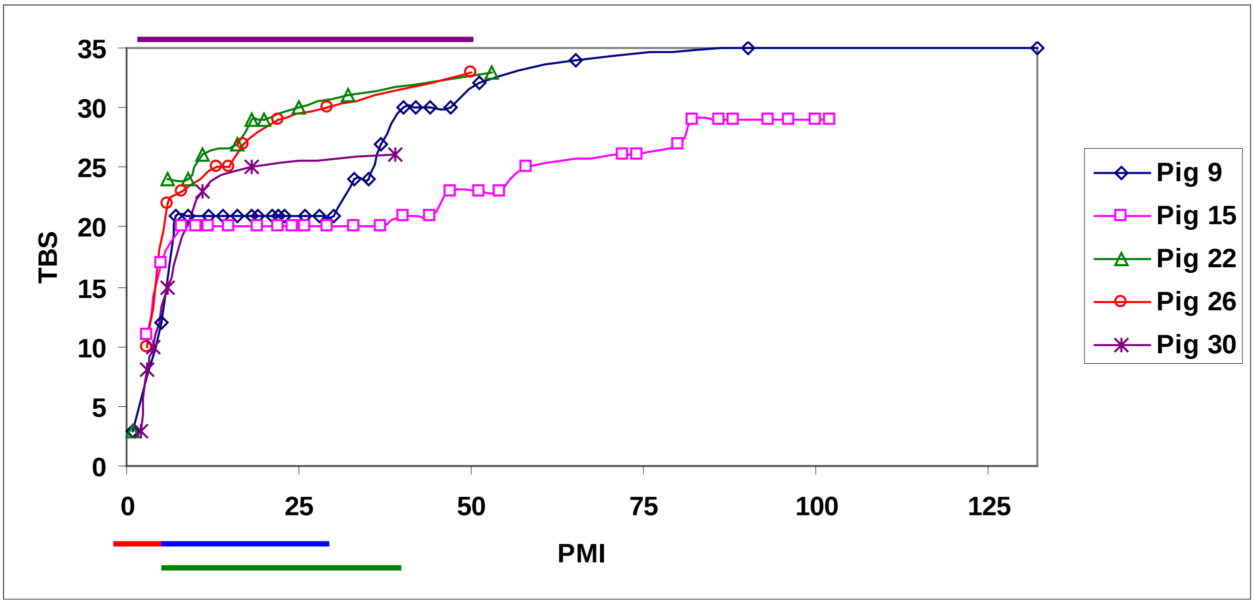

Figure 4.8. Scatter plots of TBS vs. PMI (in calendar days) for five summer pigs.

In summer pig 9 (see Figure 4.8), early decomposition went quickly (red line) and reached a plateau in the advanced decomposition phase (blue line). This corresponds with season changes (winter to summer) and day and evening temperature fluctuations. Pigs placed within this period had decomposition patterns more similar to that of the winter sample. More rapid decomposition of late winter and early summer pigs did not appear until after October rainfall, when the desiccated tissues were remoistening and the carcasses were re-infested with insects.

Rainfall did not necessary cause an increase in decay. For example, pig 15 was placed on 27 October 2008. The early plateau phase (green line in Figure 4.8) may have been caused by long periods of rainfall from late October through November. Pig carcasses which received rainfall in the early phases of decomposition (pigs 12, 13, 14 and 15) were saturated and mouldy. Furthermore, the number of insects which had fed on the remains was drastically reduced (Figure 4.9, 4.10). Once the tissues had dried, they were re-infested by insects and the process of decomposition resumed.

Figure 4.9. Slowed rate of decomposition in pig 13 (27 days after placement) with moist tissues from summer rainfall.

Figure 4.10. The appearance of mould on pig 12 after rainfall (26 days after placement).

During the peak months of summer (October to January), the days and nights were consistently warmer. The decomposition pattern changed to an exponential curve in pigs placed during this period e.g. pigs 22, 26 and 30 (Figure 4.8) and pigs 19 to 21, 23 to 25 and 27 to 29 (Appendix B.3, page 100). Initially decomposition occurred rapidly and leveled off within a PMI of 10 to 15 days; most pigs were almost skeletonized before a PMI of 60 days was reached (purple line in Figure 4.8). Unlike the winter pigs, no plateau period was observed. This accelerated rate of decomposition without a plateau phase was probably due to short periods of rain and consistently higher temperatures in the late summer months.

In Figures 4.11 and 4.12, the decomposition pattern, when ADD was plotted against TBS, is shown for the complete summer sample (n=22) and for the five example summer individuals. (For the individual scatter plots refer to Appendix B.4 (pp 104). Again, similar to the scatter plots for the winter pig data, ADD seemed to produce similar results to that of the PMI plots (see Figures 4.7 and 4.8).

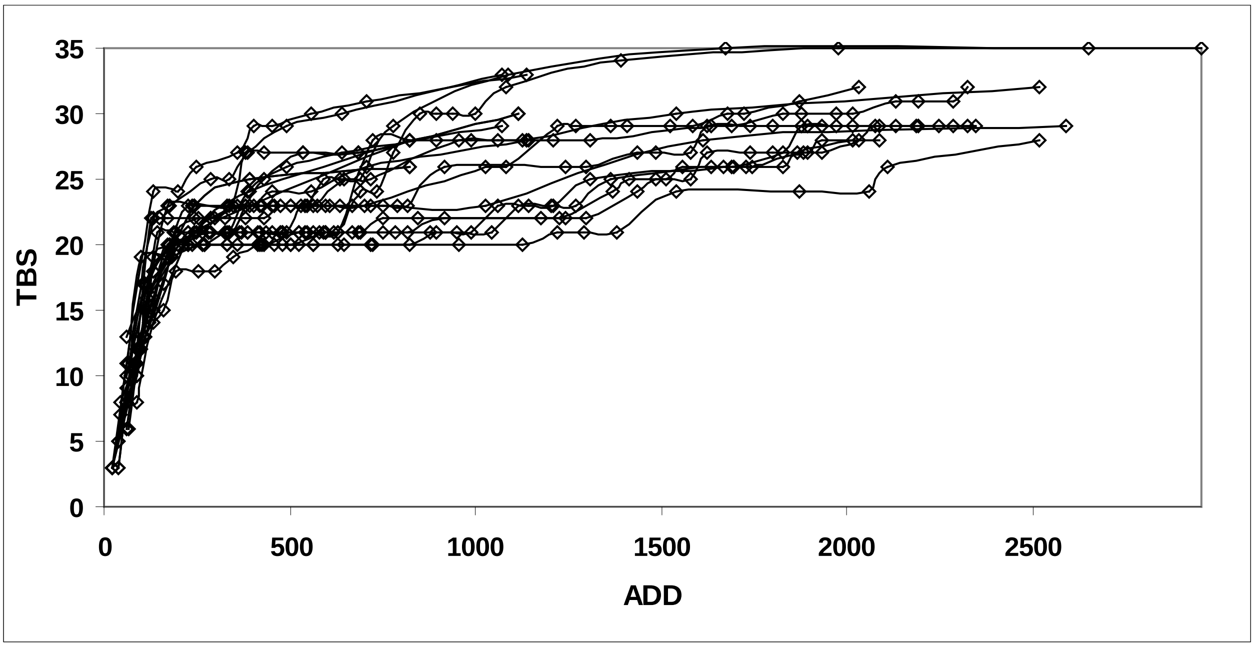

Figure 4.11. Scatter plot of TBS vs. ADD for all summer pigs.

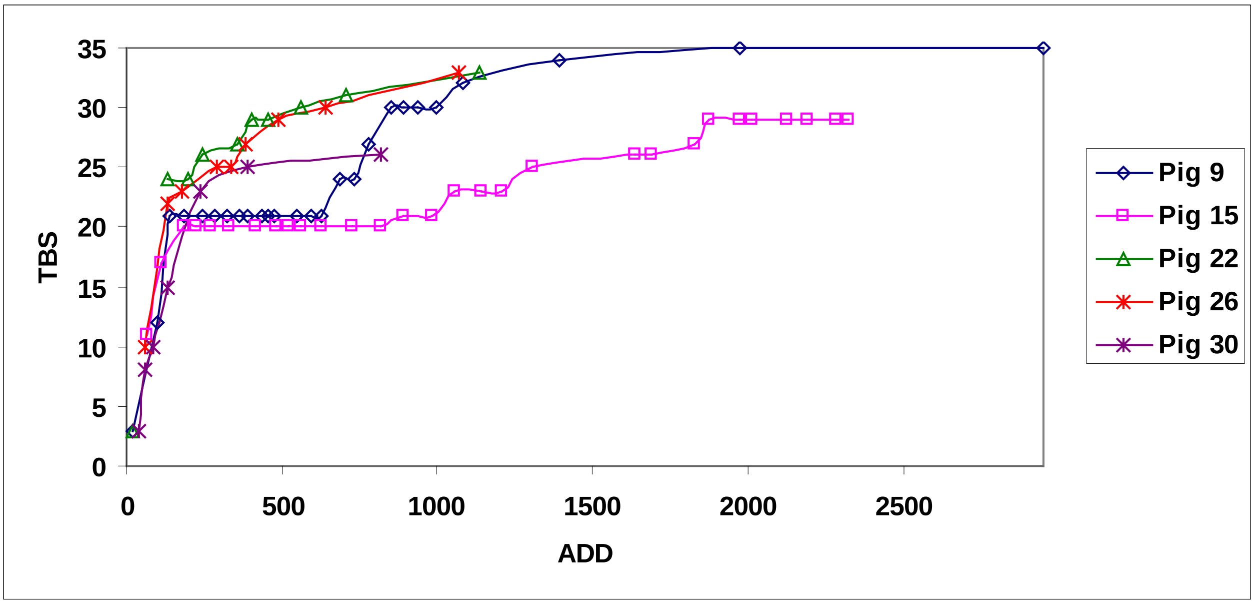

Figure 4.12. Scatter plot of TBS vs. ADD for five summer pigs.

4.3. Random-Effects Maximum Likelihood Regression Analysis of pig data

The abovementioned scatter plots of TBS vs. PMI and TBS vs. ADD showed non-linear relationships. By log transforming the PMI and ADD, a more linear curve was produced. This provided a better indication of the relationship between PMI or ADD and TBS and allowed the use of Random-effects Maximum Likelihood regression. By transforming both PMI and ADD, the equation took on the form of:

$$\text{Log}_{10}(y) = B(x) + \text{constant}$$

where B represents the slope and the constant represents the y-intercept. For this specific study, the predicted (y) was PMI or ADD and the independent (x) variable was TBS. This resulted in the following equation:

$$\text{Log}_{10}\text{ADD} = B*\text{TBS} + \text{constant}$$

Or, by raising 10 to the value expressed in the parentheses, the equation can be simplified:

$$\text{ADD} = 10^{(B*\text{TBS} + \text{constant})}$$

4.3.1. Combined/Complete data set

Log transformations produced improvements in the r-squared value for both PMI and ADD, thus demonstrating the advantage of using log transformations with curvilinear data. In Figures 4.13 to 4.16, the regression relationship of untransformed data as well as the regression of the log transformed data against TBS is shown. In the case of PMI, the r-squared value increased from

0.3656 to 0.5503 (Figures 4.13 and 4.14), while for ADD the value increased from 0.4222 to 0.6227 (Figures 4.15 and 4.16).

Therefore in the log-transformed data for TBS, 62% of the variability in decomposition is accounted for by ADD, while only 55% can be explained by PMI. Therefore, ADD is a better descriptor of the decomposition process than PMI; even though the patterns of decomposition were shown to be similar. These results can be used to emphasize the importance of temperature (in degree) and irrespective of time (in hours) on the decay process. In other words, PMI reflects the number of days that have passed since death; but, the catalyst for either a slow or rapid rate of decay is dependent on temperature. When examining temperature (ADD) and days (PMI) within a season, a closer statistical relationship is anticipated due to the fact that temperature fluctuations are being controlled within a 'cold' or 'warm' season.

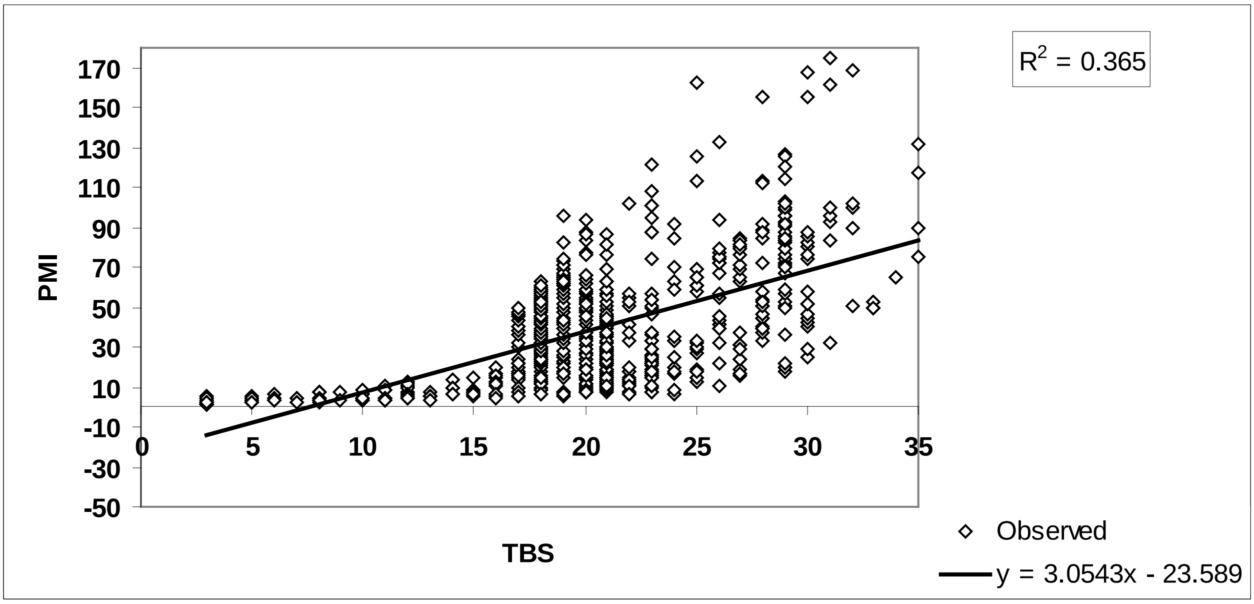

Figure 4.13. PMI vs. TBS for all pigs indicating the regression relationship of untransformed data.

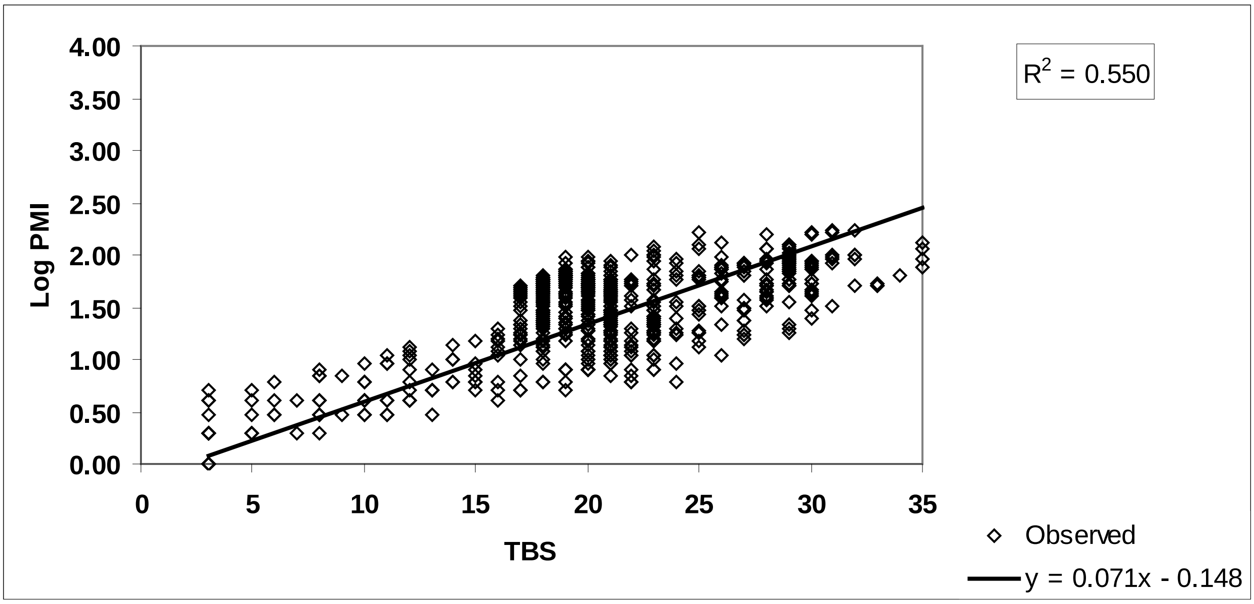

Figure 4.14. LogPMI vs. TBS for all pigs.

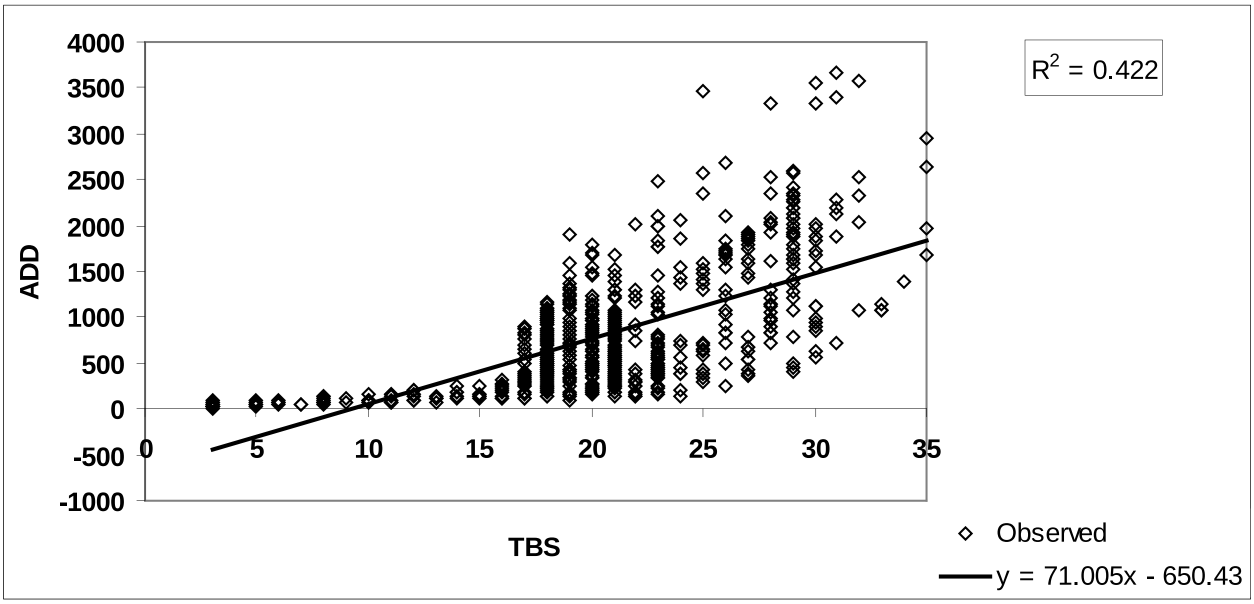

Figure 4.15. ADD vs. TBS for all pigs indicating the regression relationship of untransformed data.

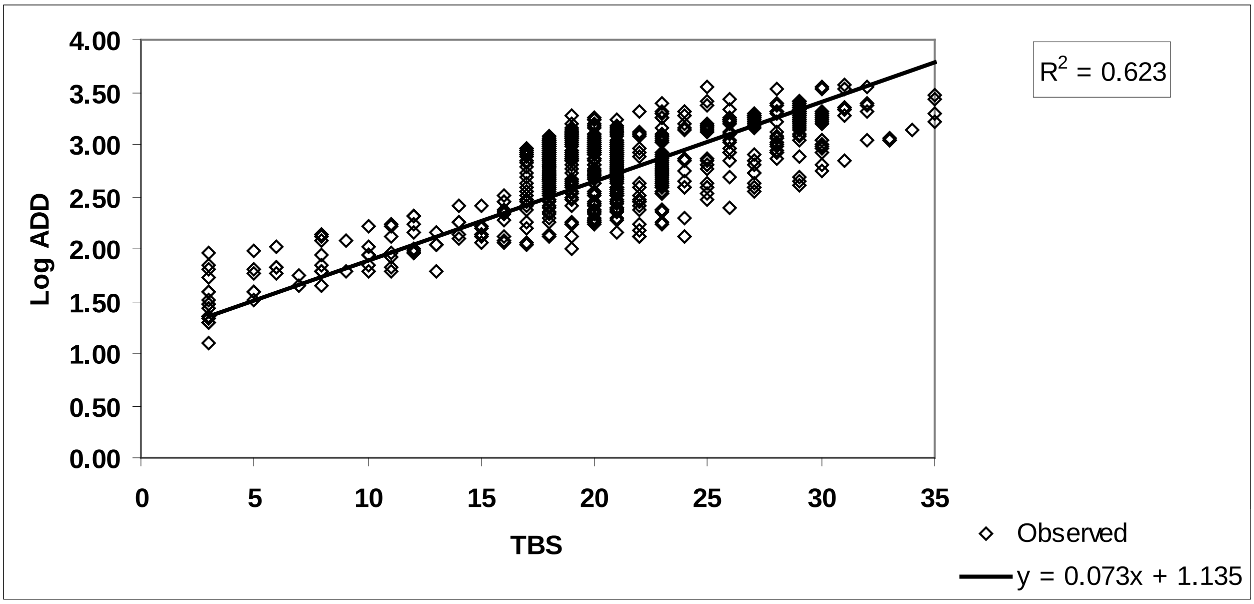

Figure 4.16. LogADD vs. TBS for all pigs.

4.3.2. Winter pig data

Random-effects Maximum Likelihood regression lines of untransformed data for winter pigs (Figure 4.17) yielded an r-squared value of 0.5824. Therefore, 58% of the variation observed in decomposition (i.e., the TBS) can be explained by PMI. By using the logarithmic curve seen in Figure 4.18, the r-squared value improved to 0.786, or 79%. Similarly the r-squared values improved, by using the logarithmic curve, from 0.555 to 0.7853, when the ADD was plotted against TBS (Figures 4.19 and 4.20). This suggests that PMI is an equally good descriptor of decomposition as ADD during the winter period. These similarities in r-shaped values for temperature (unit of degrees) and PMI (unit of days) are related to the examination to the isolation of relatively constant temperatures within a seasons

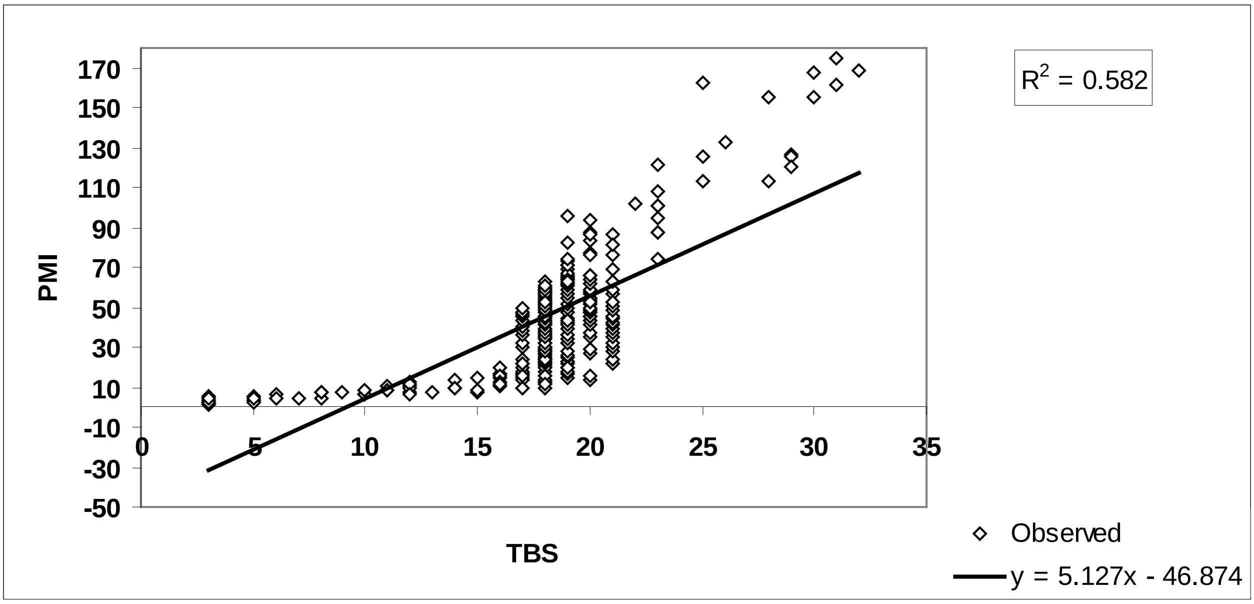

Figure 4.17. PMI vs. TBS for the winter period.

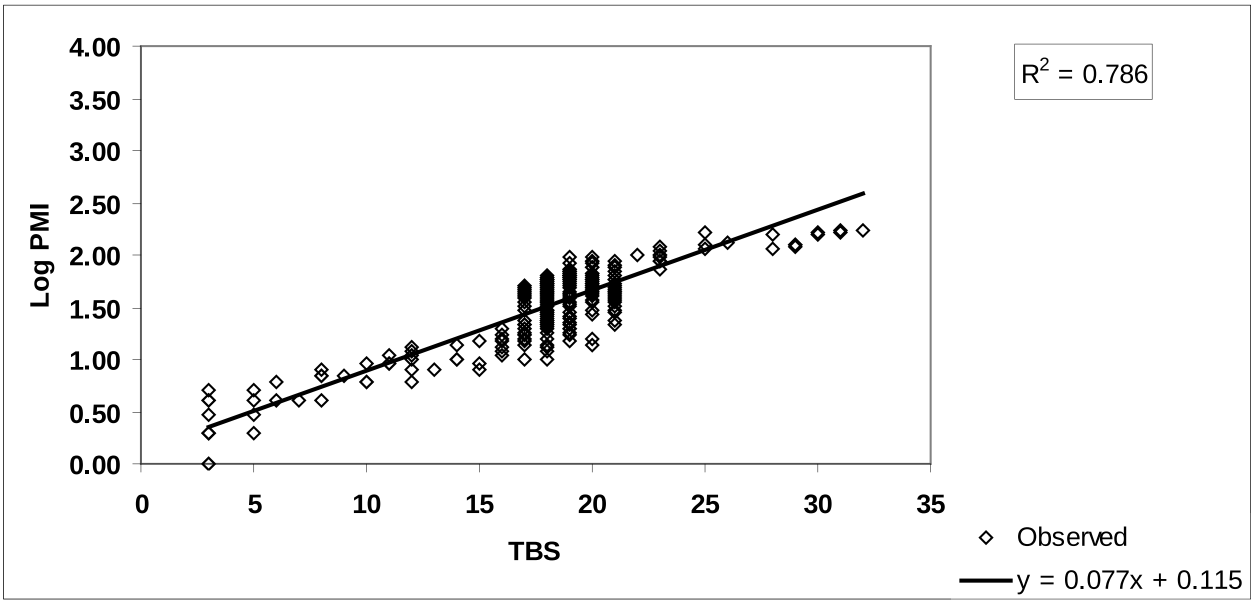

Figure 4.18. LogPMI vs. TBS for the winter period.

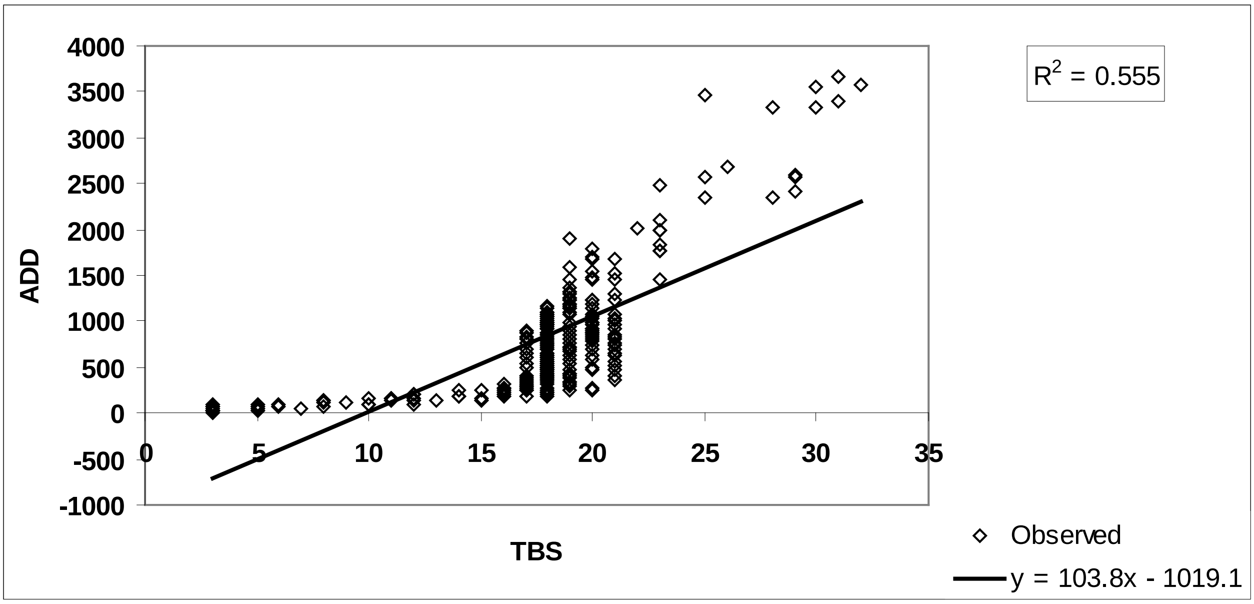

Figure 4.19. ADD vs. TBS for the winter period.

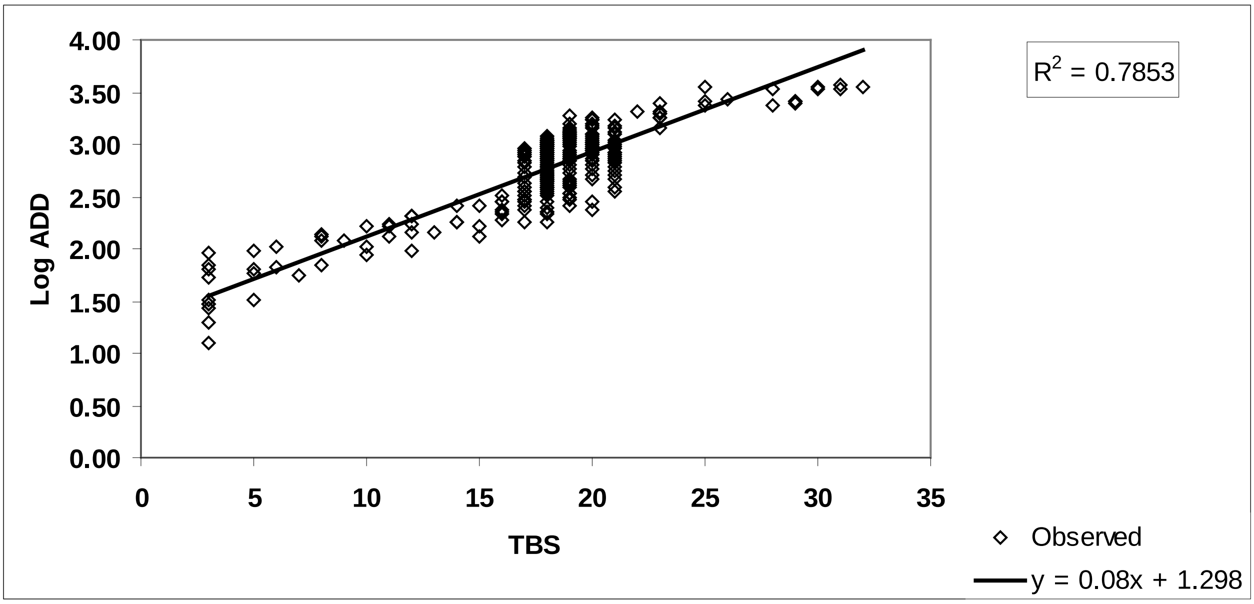

Figure 4.20. LogADD vs. TBS for the winter period.

4.3.3. Summer pig data

The r-squared values improved from 0.4964 to 0.7487 and from 0.4901 to 0.7515, respectively, when PMI and ADD were regressed against TBS using the logarithmic curve (Figures 4.21, 4.22, 4.23 and 4.24). Compared to the winter pig dataset, the correlation between TBS and both PMI and ADD was similar.

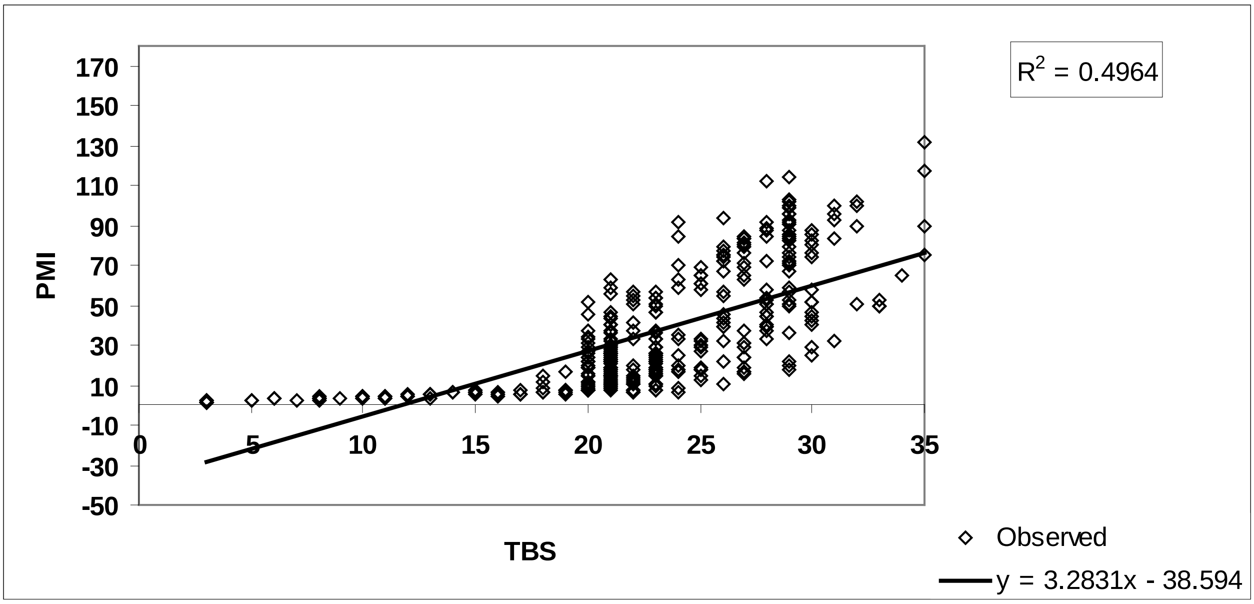

Figure 4.21. PMI vs. TBS for the summer period.

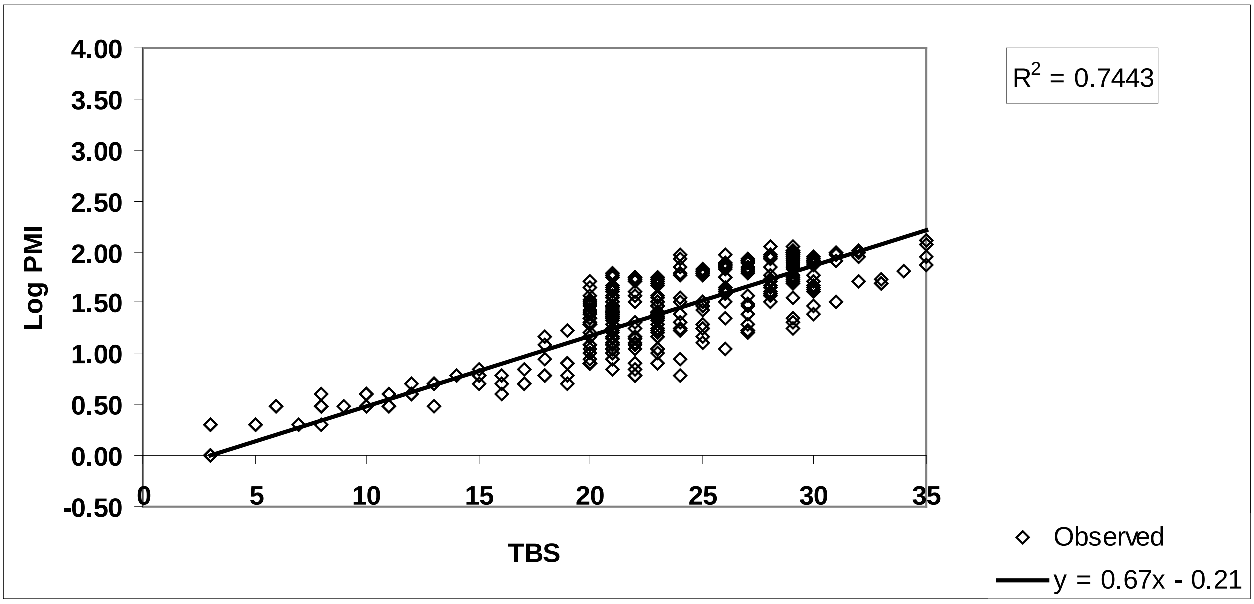

Figure 4.22. LogPMI vs. TBS for the summer period.

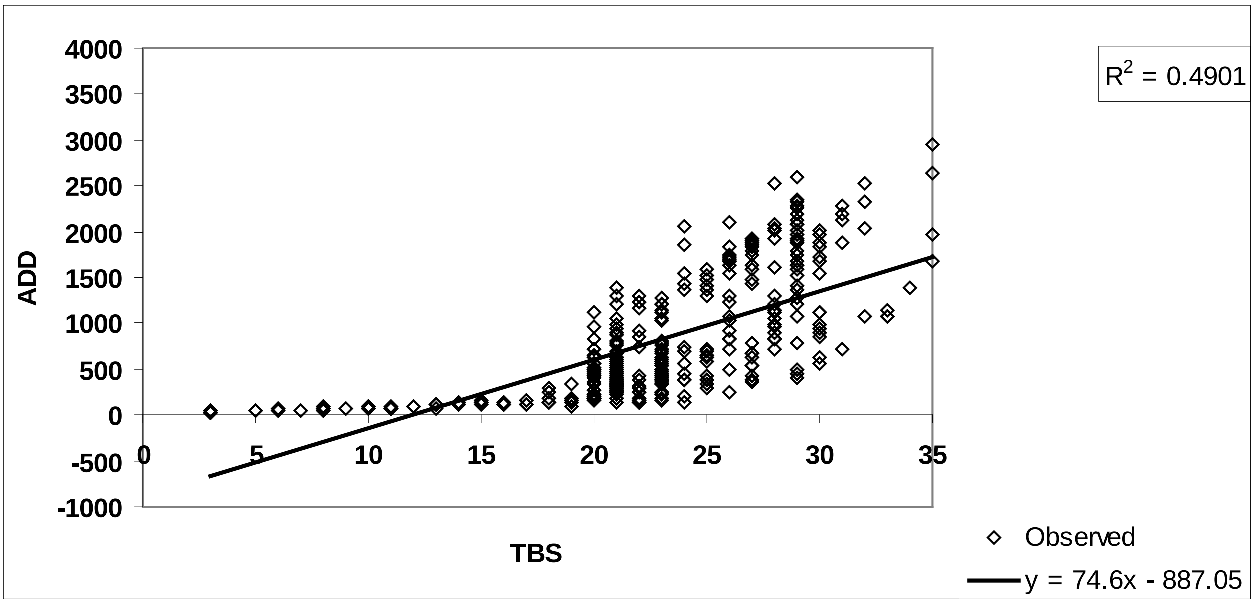

Figure 4.23. ADD vs. TBS for the summer period.

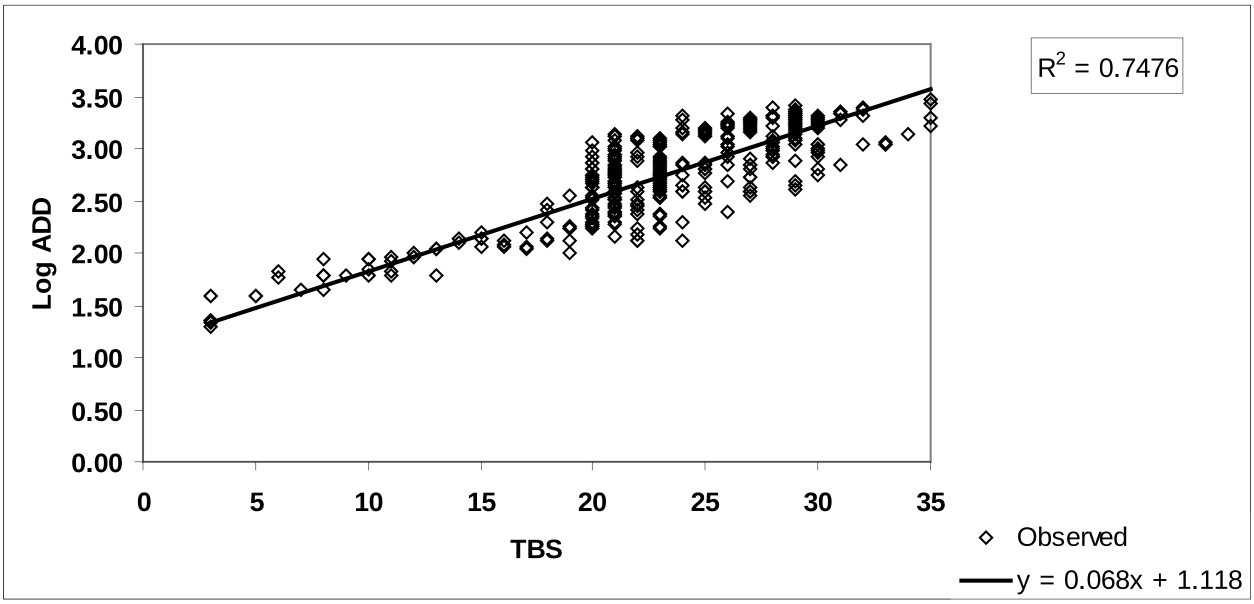

Figure 4.24. LogADD vs. TBS for the summer period.

4.3.4. Seasonal data

In Figure 4.25, the seasonal distribution of decomposition is shown for the entire dataset when LogADD is regressed against TBS. For the early TBS scores, the rate of decomposition is similar with a difference only being observed at a TBS of 17 and greater. The summer period achieved higher TBS values in a shorter period of time than the winter period. For example, at 1500 ADD, the TBS range for the summer period was 23 to 34 (pink data) whereas the TBS range for winter pigs was 17 to 23 (blue data) (Figure 4.25). Additionally, the summer period displayed more variability that the winter period; this may be attributed to increased insect activity and humidity during the summer months.

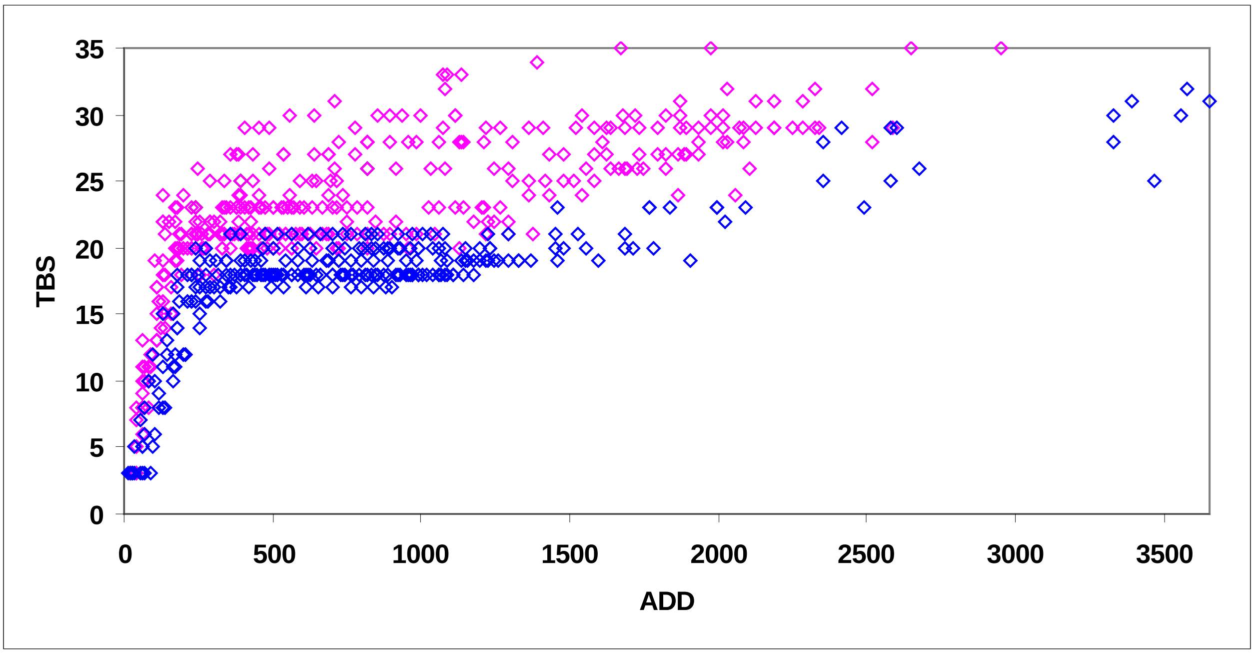

Figure 4.25. ADD vs. TBS for the entire pig dataset indicating the difference in seasonal distribution between winter (blue) and summer pigs (pink).

Using the above mentioned regressions, predictive equations were developed that can be used to calculate the estimated ADD for an unknown case. The predictive equations for the winter pigs are:

$$ADD = 10^{(0.081*TBS + 1.298)}$$

and for summer:

$$ADD = 10^{(0.068*TBS + 1.118)}.$$

A single Random-effects Maximum Likelihood regression model was produced by coding season with a numerical scale (0 for winter and 1 for summer). ADD was estimated using the following equation:

$$ADD = 10^{[1.298 + 0.081*TBS - 0.180*Season - 0.013(TBS*Season)]}$$

Similarly PMI can be predicted using:

$$PMI = 10^{[0.115 + 0.077*TBS - 0.325*Season - 0.010(TBS*Season)]}$$

The resulting r-squared values for both these regressions, using the new model which includes knowledge of the season, are 0.7652 and 0.7677, respectively, which is considerably higher when compared to the r-squared values for the Random-effects Maximum Likelihood regression (0.6227 for ADD and 0.5503 for PMI), of the entire dataset. As expected, formulae based on seasonal data appeared to be more accurate at estimating time since death as large temperature fluctuations, which were seen when the seasons are combined, were not controlled for when the seasons were analyzed separately. These values as well as different r-squared values and variables of the formulae for the seasons and the whole year are summarized in Table 4.3.

Table 4.3. Regression relationships of log transformed PMI and ADD vs. TBS for seasons and interaction of TBS and season

Regression	Prediction	Coefficients		r^2 values	
		LogPMI	LogADD	LogPMI	LogADD
Linear: Winter	TBS Intercept	0.077 0.115	0.081 1.298	0.786	0.785
Linear: Summer	TBS Intercept	0.067 -0.21	0.068 1.118	0.749	0.751
Linear: All	TBS Intercept	0.071 -0.148	0.073 1.135	0.550	0.622
Multivariate: All (interaction of season)	TBS Season TBS*Season Intercept	0.077 -0.325 -0.010 0.115	0.081 -0.180 -0.013 1.298	0.768	0.765

In the majority of circumstances in which the season is not known, one should use the Random-effects Maximum Likelihood regression for the entire dataset:

$$\text{ADD} = 10^{(0.073*\text{TBS} + 1.135)}$$

and

$$\text{PMI} = 10^{(0.071*\text{TBS} - 0.148)}$$

The formula for estimated ADD can be used in any geographical region. The ADD formula uses temperature data from weather stations to calculate the PMI. The average daily temperatures (i.e., the ADD) are added until estimated ADD equals the actual ADD. The number of days that it took for this to happen represents time since death or PMI. If weather station data or temperature data is not available, the PMI formulae can be used, but it is to be less reliable. This is because the temperature, or ADD, and not the PMI is driving the rate of decay. Additionally, the PMI formula has been designed in the unique micro-climate of the FABF, and thus would be less accurate in other areas of the country, when temperature data is not available.

Using all possible combinations of the predicted TBS values, the ADD forecasts were produced from the equation for all data points without the interaction of season (Table 4.4). Along with these values, the upper and lower limit forecasts within the 95% confidence interval were developed. These values represent the estimated ADD values for each TBS observed from the Random-effects Maximum Likelihood regression equation: ADD = $10^{(0.073*TBS + 1.135)}$ as well as the standard error for each TBS. For example, if a body with an unknown season of death is received and it is determined that the TBS value is five, the estimated ADD is 31.41 or between 24.98 and 39.48. The result is an estimated PMI of approximately 4 and 7 days with an average of 6ºC.

Table 4.4. Forecast of ADD as well as the corresponding upper and lower limits within the 95% confidence interval without the interaction of season.

TBS	ADD	ADD (95% Convidence Interval) Lower Limit	Upper Limit
3	22.49	17.80	28.43
4	26.58	21.09	33.50
5	31.41	24.98	39.48
6	37.11	29.59	46.54
7	43.85	35.05	54.87
8	51.82	41.50	64.70
9	61.23	49.14	76.31
10	72.36	58.17	90.00
11	85.5	68.85	106.17
12	101.03	81.49	125.26
13	119.38	96.42	147.81
14	141.07	114.08	174.44
15	166.69	134.94	205.91
16	196.97	159.60	243.09
17	232.75	188.72	287.04
18	275.02	223.13	338.98
19	324.98	263.77	400.40
20	384.01	311.75	473.03
21	453.77	368.40	558.92
22	536.19	435.26	660.52
23	633.59	514.18	780.73
24	748.68	607.30	922.97
25	884.67	717.16	1091.31
26	1045.37	846.75	1290.56
27	1235.25	999.60	1526.46
28	1459.63	1179.85	1805.77
29	1724.77	1392.37	2136.52
30	2038.07	1642.91	2528.27
31	2408.27	1938.23	2992.30
32	2845.72	2286.30	3542.03
33	3362.64	2696.47	4193.39
34	3973.45	3179.77	4965.24
35	4695.21	3749.16	5879.98

Using this same method, the ADD forecast and 95% confidence interval was created with the effect of season incorporated (Table 4.5). Therefore, if death was known to have occurred during winter, then only the ADD forecast for that season needs to be used.

Table 4.5. Forecast of ADD as well as the corresponding upper and lower limits within the 95% confidence interval without the interaction of season for the winter period.

		ADD (95% Convidence Interval)	
TBS	**ADD**	**Lower Limit**	**Upper Limit**
3	34.76	26.05	46.39
4	41.9	31.55	55.65
5	50.52	38.22	66.78
6	60.9	46.27	80.16
7	73.42	56.00	96.24
8	88.51	67.77	115.60
9	106.7	81.98	138.88
10	128.63	99.13	166.91
11	155.07	119.83	200.67
12	186.94	144.81	241.34
13	225.37	174.93	290.36
14	271.69	211.23	349.46
15	327.53	254.97	420.75
16	394.86	307.65	506.78
17	476.02	371.07	610.64
18	573.86	447.39	736.06
19	691.81	539.20	887.60
20	834	649.59	1070.76
21	1005.42	782.29	1292.20
22	1212.08	941.73	1560.04
23	1461.21	1133.24	1884.10
24	1761.55	1363.19	2276.31
25	2123.61	1639.22	2751.14
26	2560.1	1970.46	3326.19
27	3086.31	2367.84	4022.78
28	3720.67	2844.44	4866.84
29	4485.42	3415.89	5889.83
30	5407.36	4100.94	7129.97
31	6518.79	4921.96	8633.69
32	7858.67	5905.74	10457.40
33	9473.95	7084.33	12669.60
34	11421.2	8496.05	15353.56
35	13768.8	10186.71	18610.43

Table 4.6. Forecast of ADD as well as the corresponding upper and lower limits within the 95% confidence interval without the interaction of season for the summer period.

TBS	ADD	ADD (95% Convidence Interval) Lower Limit	Upper Limit
3	20.97	17.05	25.78
4	24.52	20.04	30.01
5	28.68	23.54	34.93
6	33.54	27.65	40.67
7	39.22	32.47	47.36
8	45.86	38.13	55.16
9	53.63	44.76	64.26
10	62.72	52.54	74.88
11	73.35	61.65	87.27
12	85.78	72.33	101.73
13	100.31	84.83	118.62
14	117.31	99.47	138.35
15	137.19	116.60	161.41
16	160.44	136.65	188.37
17	187.62	160.09	219.90
18	219.41	187.49	256.78
19	256.59	219.51	299.94
20	300.07	256.92	350.47
21	350.92	300.60	409.66
22	410.38	351.59	479.00
23	479.92	411.09	560.27
24	561.24	480.49	655.55
25	656.33	561.43	767.28
26	767.55	655.79	898.36
27	897.61	765.75	1052.16
28	1049.7	893.88	1232.68
29	1227.57	1043.13	1444.61
30	1435.58	1216.95	1693.47
31	1678.83	1419.34	1985.75
32	1963.3	1654.96	2329.09
33	2295.97	1929.20	2732.47
34	2685.01	2248.35	3206.48
35	3139.98	2619.71	3763.57

For example a TBS value of 5, during winter, provides an estimated ADD of 50.52, while for this TBS score, ADD is only 28.68 for the summer period. As expected more temperature degrees are needed to accumulate before they are comparable to the warmer summer period.

In both these models the upper and lower limit forecast for ADD becomes wider as the TBS becomes higher. This is expected since the decomposition pattern was more variable in the later stages of decomposition (i.e. higher TBS values) as seen in Figures 4.2, 4.3, 4.4, 4.6, 4.7 and 4.11.

4.4. Inter-observer error

Inter-class correlation is a measure of inter-rater agreement using the Pearson's correlation test. Ideal results for these tests are to obtain an r value of 1.00, which indicates that the method can be consistently and accurately repeated 100% of the time. According to Allen (1982), any value classified over 0.75 is considered a high correlation.

The raw data of the head and neck scores, trunk scores, limbs scores and the total body scores provided by the primary and the secondary observers for the first ten pigs can be found in Appendix D (pp 128). As seen in the raw data, the TBS scores were seldom different between the two observers; even though scores for one or more of the individual anatomical regions may have differed by one value. This resulted in TBS scores that were the same in certain instances, even though the scores for the various regions differed.

The values produced by the Pearson's correlation test suggest that the descriptions for the different regions are clear enough so that individual scores and the TBS can be repeated (Table 4.6). In general, TBS has the highest r-value of all the description scores and thus was correctly repeated 99.2% of the time. While the individual regions had lower r-values than that of the TBS, the r-values remained high (0.981 for head and neck, 0.985 for trunk and 0.990 for the limbs), indicating that this method is highly repeatable between observers. Intra-observer error was not to be tested since the first and second scoring of a pig had to occur on the same day. Due to the small number of pigs and the limited variables scored, the researcher may have remembered the description and score for each variable on a specific pig.

Table 4.7. Correlation coefficients for the inter-observer results.

Description score	Correlation coefficient
Head and Neck	0.981
Trunk	0.985
Limbs	0.990
Total Body Score	0.992

Chapter 5: Discussion

The use of Accumulated Degree-Days to estimate the post-mortem interval has become a popular technique amongst forensic anthropologists, especially in North America (Vass *et al.*, 1992; Parsons, 2009; Megyesi *et al.*, 2005; Schiel, 2008; Fitzgerald and Oxenham, 2009). To date, the method developed by Megyesi *et al.* (2005) has been repeated in various geographical area including West Central Montana (Parsons, 2009), Iowa and Indiana (Schiel, 2008).

The aim of this study was to evaluate the method of Megyesi *et al*. (2005) in which Total Body Scores (TBS) and Accumulated Degree-Days (ADD) were applied to estimate the post-mortem interval (PMI) in South Africa. To achieve this aim, data on the quantitative variables, TBS and ADD, were collected over a period of 8 months (August 2008 to March 2009). Scatter plots were used to describe the pattern of decomposition, (see Figures 4.2 to 4.5, 4.7 to 4.10 and 4.13 to 4.15), and log linear regression formulae were developed in which TBS was used to estimate ADD and PMI. Additionally, the repeatability in scoring the stages of decomposition, also referred to as TBS, was examined.

Similar to other studies (e.g. Megyesi *et al*., 2005; Schiel, 2008), the rate of decomposition for the entire dataset was found to be curvilinear rather than linear. The rate of decomposition increased in a linear fashion but became variable in advanced stages when TBS was greater than 17. When the data were split into seasons, the summer period had a shorter early decomposition phase with an increase in variability after a TBS of 20 (Figures 4.13 and 4.15); in contrast, the winter pigs had a distinct plateau phase in which little to no decomposition occurred after a TBS of 16. These differences may be attributed to increased insect activity, increased humidity and rainfall during the summer months.

Since the data followed a curvilinear pattern, log transformation was used to facilitate the Random-Effects Maximum Likelihood regression analyses. A large proportion of the variation found in the TBS scores was explained with ADD ($r^2 = 0.768$) and PMI ($r^2 = 0.765$). Morphological changes in the body, similar to changes in the distribution of fatty acids or insect activity, are quantifiable. Therefore, they can be used to estimate the post-mortem interval.

The purpose of this discussion is four fold. Firstly, the patterns of decomposition are discussed and comparisons are made with other quantitative studies that employed the combination of TBS and ADD to estimate PMI. Also the effects of seasonality and rainfall are compared to that of other studies. Secondly, the possible variables, aside from temperature, that can influence the pattern and rate of decomposition, are discussed. Thirdly, and the possible limitations and advantages of using pig models in forensic science also is addressed. Lastly, the applicability of this research to forensic case work in South Africa is discussed.

5.1 Interpreting patterns of decomposition

Since the publication of the retrospective study by Megeysi *et al.* (2005), many studies using longitudinal decomposition data from pig carcasses have been conducted in different climates. By measuring the decomposition rate as reflected by the TBS against ADD, research into the rate of decay, and the factors that influence it, can be standardized and thus their reliability and accuracy improved (Schiel, 2008; Simmons, 2010). Simmons *et al.* (2010) stated that research using ADD "enabled researchers to align the processes occurring under different conditions, which will enhance the ability of other researchers to replicate the experiments and test the results". Furthermore, these authors suggest that variables such as temperature and season can be eliminated as they are taken into account with the use of ADD. The accumulation of temperature, or heat degree units, within a particular season should be constant in that season, and thus similarities in the contribution of this influence to the decomposition pattern, or TBS, should remain comparable between distinct demarcated periods of temperature changes, i.e. summer or winter.

In this study, ADD accounted for approximately 76% of the variability in decomposition, which is similar to 80% observed by Megyesi *et al.* (2005) and 78% by Schiel (2008). Other factors, such as rainfall, insect activity and accessibility of the carcass to predators, also contributed to the rate of decay as well as its macroscopic manifestations.

With the inclusion of seasonality into the linear regression equations, slight variation among the results of this study and those of Schiel (2008) were observed. In this study, r-squared values between TBS and ADD for winter (r = 0.78) and summer (r = 0.75) periods were similar to each other; this is in contrast to Schiel (2008) in which the r^2-values for the winter (0.823) were much greater than those for the summer (0.591).

When assessing differences between the combination data versus the seasonality data, Schiel (2008) noted little to no improvement in ADD to TBS, $r^2 = 0.732$ (for seasons) and $r^2 = 0.786$ (for no season). In contrast, this study demonstrated an improvement in the r^2-value for ADD (0.6227 to 0.7652) when seasonality was incorporated. Differences may be attributed to the period of time in which the pigs were observed, the number of pigs observed, as well as the severity of change between seasons in these two areas. For instance, the presence of snow in a North American winter versus the presence of summer rains in certain regions of South Africa.

For example, rainfall appeared to contribute greatly to the process of decomposition. In Pretoria, South Africa, rainfall occurred primarily during the summer months (October to February). Seasonally rainfall was shown to contribute to the rate of decomposition such that winter pigs were re-moistened and re-infested with insects, whereas the summer pigs were over-saturated and generally avoided by insects. Thus seasonal features, such as rainfall in South Africa or snow in

North America, are to have an effect on the behaviors of insects and, in turn, on the rate of decomposition.

In Figure 5.1, the effect of rainfall on the decomposition of a winter pig, for which the tissues became desiccated, and a summer pig, for which the tissues permanently remained in an active stage of decay. The presence of damage by beetles, which is associated with dry tissues and a slow down in decomposition, was observed on a carcass in the beginning of summer. When temperatures became warmer and the dried tissue was re-hydrated from the rain, insects re-infested the corpse (see Figure 5.2). In this case, rainfall contributed to kick-starting the process of decay from advanced to skeletonization. On the other hand, rainfall caused fresh and early decomposed remains to become oversaturated and mouldy. Insects avoided these wet corpses; a circumstance which slowed down the decomposition process (see Figure 5.3).

Authors have mentioned that rainfall has an effect on the rate of decomposition in that it indirectly influences both insect activity and temperature (Reed, 1958; Mann *et al.*, 1990; Lopes De Carvalho and Linhares, 2001; Archer, 2004). In one pig, Schiel (2008) observed that precipitation during the period of advanced decay resulted in rapid decomposition due to the fact that tissue desiccation was prevented and decay could continue. These observations are most comparable to summer rainfall re-moistening of tissues of winter pigs in South Africa; which permitted a continuation in decomposition.

a.) b.)


Figure 5.1. Differences in the stage of advanced decomposition between a winter pig (a) at a TBS of 18 and PMI of 54 days and a summer pig (b) at a TBS of 21 and PMI 23 days.

Figure 5.2. Beetle damage to the desiccated tissue of a winter pig in advanced decomposition after rainfall.

a.)  b.)

Figure 5.3. (a) The effect of rainfall during the early stages of decomposition in a carcass that received rain (36 days after placement) compared to (b) the decomposition pattern of a pig carcass that did not receive any rainfall (30 days after placement) during summer.

Another important consideration for evaluating the seasonal rates of decomposition in this study is the absence of freezing temperatures in the Gauteng Province. During winter, average temperatures are 6 C at night and 26 C during the day (South African Weather Services). Thus winter carcasses do not freeze. The complete absent of insect activity – which would normally be present in zero or sub-zero temperatures was not observed in Pretoria. This is in contrast to many North American and European winters in which bodies freeze and only thaw during the following spring and summer months (Micozzi, 1986).

As observed in scatter plots (Figures 4.4 to 4.6) pigs placed during the winter period took longer to reach skeletonization than pigs that had been placed during the summer months. However, the decay of winter pigs did not abruptly stop, as seen in many studies, but merely slowed, or entered a plateau phase until the subsequent arrival of summer rains and warmer temperatures. This period can seen as a dormant phase and may be used to explain differences in the decomposition patterns between bodies in the colder North American regions and South Africa.

Variability in decomposition between winter and summer appears to be due to seasonal activity in insect behaviour, temperature, rainfall and humidity. Due to the longitudinal nature of the study, distinct decomposition patterns were observed in two major seasons, namely winter and summer. However, it needs to be cautioned that these modifications may not always be present and should preferably not be used to determine season of death for an unknown person. Furthermore, all the possible variables can not be predicted or compensated for but it does seem as though seasonality, and hence temperature, plays an important role in the rate of decay.

5.2 Factors influencing the pattern and rate of decomposition

Additional factors observed that may have influenced the rate of decomposition include both scavenger and insect activity.

5.2.1. Scavenger activity

During decomposition studies, the presence and activity of scavengers has been widely reported (e.g., Haglund *et al.*, 1988, 1989; Galloway *et al.*, 1989; Mann *et al.*, 1990; Rossi *et al.*, 1994; Bass, 1997; France *et al.*, 1997; Galloway, 1997; Haglund, 1997a; Haglund, 1997b; Merbs, 1997; Rodriguez, 1997; Sorg *et al.* 1997). In this study, scavenger activity from larger animals, such as foxes and dogs, was prevented with a chicken wire mesh around the enclosure. Only one case of meerkat (suricates) activity was found in which skeletonized tarsal bones had been removed and were found scattered outside the enclosure.

Birds were often seen feeding directly (i.e. consuming flesh) or indirectly (i.e. consuming insects) on the carcass. While not specifically recorded, this behaviour may have caused modifications in the rate of decay. Similar to observations made by Rodriguez (1997) and Bass (1997) at the Anthropology Research Facility (ARF), larger birds, such as crows, were noted feeding on the carcasses at the FABF. Crows often removed pieces of skin on the shoulders and abdomen, which may have caused an earlier release of abdominal gases and thus an earlier post-bloat stage (see Figure 5.4). Also, these post-mortem wounds led to additional areas available for ovipositing by Diptera.

Cattle egrets and smaller birds may have caused a decrease in the rate of decomposition due to the fact that they fed on the insects and the insect's larvae. During early stages of decomposition, a stampede of approximately 80 cattle egrets could be observed feeding on maggots in and around the pig carcasses (Figure 5.5). These birds would distribute themselves over the enclosure in numbers of 8 to 15 birds per carcass.

Figure 5.4. Premature release of gases during bloating (arrow) due to damage to the soft tissues of the abdomen and removal of tissues (circles) by avian scavenger activity.

Figure 5.5. Cattle egrets feeding on the maggot mass of a pig carcass in the early stage of advanced decomposition.

5.2.2. Insect activity and migration

Maggot migration has been observed in numerous studies on decomposition (Vass *et al.*, 1992; Haskell *et al.*, 1997; Wagster, 2005; Kelly, 2006; Carter *et al.*, 2007). Post-feeding larvae often migrate away from the body to pupate. After pupation, the next generation of Diptera (flies) become sexually mature and start to look for a carcass on which to deposit their eggs (Haskell *et al.*, 1997). The question that arises is whether maggot activity can affect decompositional rates in smaller enclosed areas, such as the Miertjie le Roux Experimental Farm. According to Shahid *et al.*, (2003), an increase in carcasses at the Anthropology Research Facility (ARF) did not cause either an abnormally high population of insects or an increase in the colonization of sarcosaprophagous insects in comparison to surrounding regions.

However due to the small size of the facility and the large number of pigs, the rate of decomposition may have been influenced by the above-mentioned phenomenon. Even though the pigs had been placed a minimum of 10 m from each other and fresh pigs were never placed near pigs in either the fresh or early stages of decomposition, insect migration could have taken place. Due to the large number of carcasses in a relatively small region, Diptera concentrations in the area may have been larger than normal. Initially, the first Diptera species arrived in a few hours and it took approximately a day for their numbers to increase. As more pigs were placed at the site, initial arrival and an increase in insect concentrations were observed on the body in a shorter period of time. This was only observed during periods when more than one pig was placed on a single day, or pigs were placed shortly after another. Further research is required to establish whether the observed insect population concentrations would be the same in a different and larger location.

5.3. Pig models for comparison to human decomposition studies

Pig models, as substitutes for human cadavers, have widely been accepted as a means to evaluate the process of decomposition (Payne, 1968; Blair *et al.*, 1993; Terneny, 1997; Shalaby *et al.*, 2000; Schiel, 2008; Bunch, 2009; Callahan, 2009; Fitzgerald and Oxenham, 2009; Reeves, 2009). Pigs are the most suitable for studies involving decomposition due to the similarities in the internal anatomy, intestinal flora, fat to muscle ratio and the general hairlessness of the skin with humans (Goff, 1993; Byrd and Castner, 2001; Pakosh and Rogers, 2009; Reeves, 2009).

Decompositional studies using human cadavers are often retrospective in nature and longitudinal studies are, until recently, limited to the research conducted at the Anthropology Research Facility (ARF) in Knoxville, Tennessee. In contrast, pig carcasses are more readily available and therefore the sample sizes can be increased and longitudinal studies can be performed. Even though pig carcasses are increasingly used for research, it should be kept in mind that differences in anatomy, intestinal bacteria and zoonotic diseases can lead to variations in the decay process between pigs and humans. When applying the linear regression equations based on pigs to humans as a means to estimate the post-mortem interval, errors may occur.

5.3.1. Anatomy

The scoring of the pigs was difficult due to the fact that anatomical structures differed considerably between the two species. Over or underscoring of the decomposition stages for specific regions sometimes occurred since these descriptions are based on research involving human cadavers (Galloway *et al.*, 1989; Megyesi *et al.*, 2005). The most obvious differences were noted in scoring the head and limbs. Soft tissues around the nose of humans are not as dense as the snout of pigs, the limbs are shorter and have less musculature than the longer, more defined legs of humans, also the presence of hooves instead of fingers and toes do not fit with the described criteria. For example, skin slippage of hands and/or feet during early decomposition cannot take place in pigs as the hooves only break down during advanced stages of decomposition.

As already mentioned, the accuracy of the scoring method remained high even though errors in the descriptions were observed. However, the degree to which the accuracy of this method is influenced by an over and underscoring of specific areas with the TBS remaining unchanged is not known, but it is expected that the difference is not to the extent that these quantifiable features cannot be effectively used.

5.3.2. Bacteria and disease

Another difference between humans and pigs is the larger and different type of bacterial load found in the pig abdomen. Due to the difference in the intestinal flora, pigs started bloating within a very short period of time after death (12 hours to 2 days). Megyesi *et al.* (2005) placed bloating at a score of four for the trunk. In this study, bloating was observed to occur while the tissues were fresh with pink discoloration (i.e., at a score of between one and two).

Death from bacterial illnesses may have affected the rate of decay for pigs 4 and 5. Pig 4 decomposed much more quickly during winter than the other pigs, while pig 5 decomposed at the slowest rate of all pigs in the sample. Additionally when placed on the farm, Pig 4 was slightly underweight and Pig 5 had a bloody discharge coming from its abdomen. Specific infections were not possible to determine without causing external wounds to the carcass, but major deviations from the normal rate and pattern of decomposition may be an indicator of an infection.

5.4. Applying ADD in a South African Setting

Forensic anthropologists in South Africa often receive human remains that are in a stage of advanced decomposition. Under these circumstances the determination of PMI can be important to help narrow down the number of potential victims and to help understand the taphonomic influences (e.g. damage caused by scavengers, environmental factors etc) that had an effect on the body from death to discovery.

Due to a lack of information on the morphology and rate of decomposition in a South African climate, research involving methods to determine PMI from decomposed remains are extremely beneficial. Forensic pathologists and anthropologists can apply these results to bodies discovered in the whole of South Africa. However, the formulae from this study should be tested on human remains to determine the accuracy at which it can be reliably applied in a forensic context.

Chapter 6: Conclusion

This study investigated the use of Accumulated Degree-Days to estimate the post-mortem interval. Regression formulae were developed to determine whether this method can be repeated and applied in South Africa. The sample comprised of 30 pigs (*Sus scrofa*) whom had died of natural causes. The rate and pattern of decomposition (TBS) were recorded for a period of 8 months at the Miertjie Le Roux Experimental Farm of the University of Pretoria in South Africa.

The initial pattern of decomposition produced for the entire dataset was linear during the earlier stages and became more variable after a TBS value of 17. The decomposition pattern observed in the summer pigs was exponential with skeletonization rapidly being reached in most of the pigs. The winter pigs displayed a more sigmoid curve. The rate of decomposition was initially exponential and then halted during the advanced stages. The plateau phase continued until the appearance of warmer day time temperatures and summer rainfall; after which decomposition continued again.

Using log-transformations of PMI and ADD resulted in an improvement in r-values for both winter and summer datasets. For the winter pigs, PMI was an equally good descriptor of decomposition as ADD, which is reflected in similar r^2 values (0.786 and 0.785, respectively). Similar results were obtained for the summer pig dataset with correlations for PMI and ADD being more or less similar (r^2= 0.7487 and 0.7515 respectively).

For the entire dataset, ADD accounted for more of the variation seen in decomposition than PMI (55% for PMI and 62% for ADD). Furthermore, a single Random-effects Maximum Likelihood regression model, which coded season with a numerical scale (0 for winter and 1 for summer), resulted in equations that can be used to predict ADD and PMI values for the winter as well as summer period. The resulting r^2 values for both these regressions were 0.7652 (ADD) and 0.7677 (PMI). Compared to the r^2 values for the Random-effects Maximum Likelihood regression (0.6227 for ADD and 0.5503 for PMI), there was a significant improvement. This indicates that seasonality, and hence temperature, had influenced the rate of decay.

Various factors may have influenced the decomposition pattern observed in this study; with rainfall having the most noticeable effect. Alterations in the decomposition pattern depended on the time and duration of the rainfall. Rainfall in the early stages of putrefaction decreased the rate of decay, whereas rainfall after tissue desiccation, re-established the decomposition process.

Avian scavengers may have had an influence of the rate of decomposition. Crows often caused soft tissue damage to the abdomen which resulted in premature release of decompositional gases and thus a possible increase in decomposition. Cattle egrets, on the other hand, may have caused a decrease in decomposition due to the consumption of maggot masses responsible for soft tissue consumption.

The results from this study broadly agreed with those from Megeysi and colleagues (2005) as well as Schiel (2008) in that ADD accounted for approximately 76% to 80% of the variation seen in decomposition. Even though using a pig model has some limitations, the method was successfully applied in South Africa.

Future recommendations:

Future research should include the use of a larger sample over a longer period of time. For example, decomposition could be observed over a period of two years instead of 8 months to determine whether similar results can be obtained between two similar seasons (i.e. data from one winter period can be compared to data from a previous winter period).

The effect of rainfall and humidity on the rate of decomposition should be further investigated. This is probably of particular importance in a relatively dry country such as South Africa, where short, intense bursts of rain occur with alternating dry spells.

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APPENDIX A: Temperature data from the on site data logger and South African Weather Services.

Date	Min Temp	Max Temp	Ave Temp
08-13-2008	2.3	23.00	12.7
08-14-2008	2.3	25.70	14
08-15-2008	3.9	25.50	14.7
08-16-2008	4.7	25.80	15.3
08-17-2008	10.4	21.30	15.9
08-18-2008	8.8	17.90	13.4
08-19-2008	6.3	19.30	12.8
08-20-2008	5.5	25.10	15.3
08-21-2008	9.6	25.70	17.6
08-22-2008	8.9	27.80	18.4
08-23-2008	9.3	28.20	18.8
08-24-2008	8.9	26.60	17.8
08-25-2008	5.8	28.10	16.9
08-26-2008	9.7	27.40	18.6
08-27-2008	6.7	28.80	17.8
08-28-2008	10.4	27.30	18.9
08-29-2008	10.4	28.70	19.6
08-30-2008	7.4	29.00	18.2
08-31-2008	6.3	25.60	15.9
09-01-2008	4.7	22.80	13.8
09-02-2008	3.9	24.00	13.9
09-03-2008	4.1	27.10	15.6
09-04-2008	3.70	29.30	16.50
09-05-2008	3.20	30.10	16.65
09-06-2008	3.20	32.00	17.60
09-07-2008	3.30	29.80	16.55
09-08-2008	7.30	35.30	21.30
09-09-2008	9.70	35.90	22.80
09-10-2008	7.00	35.50	21.25
09-11-2008	8.70	28.50	18.60
09-12-2008	9.20	21.50	15.35
09-13-2008	5.10	24.00	14.55
09-14-2008	2.20	26.00	14.10
09-15-2008	0.00	30.10	15.05
09-16-2008	5.10	31.90	18.50
09-17-2008	7.00	31.50	19.25
09-18-2008	5.80	28.00	16.90
09-19-2008	6.30	31.10	18.70
09-21-2008	1.40	21.00	11.20
09-22-2008	0.00	27.30	13.65
09-23-2008	5.10	31.80	18.45
09-24-2008	3.50	34.50	19.00
09-25-2008	9.20	31.00	20.10
09-26-2008	8.10	33.60	20.85
09-27-2008	7.30	34.90	21.10
09-28-2008	6.20	27.20	16.70

Date	Min Temp	Max Temp	Ave Temp
09-29-2008	6.20	32.60	19.40
09-30-2008	5.00	34.30	19.65
10-01-2008	10.50	35.70	23.10
10-02-2008	12.40	35.20	23.80
10-03-2008	12.00	34.50	23.25
10-04-2008	8.30	29.20	18.75
10-05-2008	9.90	30.10	20.00
10-06-2008	11.10	27.30	19.20
10-07-2008	5.70	28.70	17.20
10-08-2008	8.50	31.10	19.80
10-09-2008	10.40	32.70	21.55
10-10-2008	6.50	32.60	19.55
10-11-2008	6.50	31.60	19.05
10-12-2008	8.00	32.70	20.35
10-13-2008	9.90	37.00	23.45
10-14-2008	10.90	38.70	24.80
10-15-2008	12.80	32.00	22.40
10-16-2008	9.40	31.90	20.65
10-17-2008	12.50	33.50	23.00
10-18-2008	12.90	32.10	22.50
10-19-2008	12.70	32.80	22.75
10-20-2008	12.20	32.60	22.40
10-21-2008	11.70	33.30	22.50
10-22-2008	13.10	35.30	24.20
10-23-2008	11.50	23.80	17.65
10-24-2008	10.00	26.40	18.20
10-25-2008	10.90	27.60	19.25
10-26-2008	12.40	27.90	20.15
10-27-2008	10.00	30.50	20.25
10-28-2008	12.80	33.80	23.30
10-29-2008	11.80	33.80	22.80
10-30-2008	12.40	31.60	22.00
10-31-2008	14.20	35.00	24.60
11-01-2008	10.60	33.70	22.15
11-02-2008	13.70	35.80	24.75
11-03-2008	14.40	36.10	25.25
11-04-2008	12.30	29.80	21.05
11-05-2008	12.00	28.30	20.15
11-06-2008	12.30	34.20	23.25
11-07-2008	14.50	25.40	19.95
11-08-2008	14.90	24.80	19.85
11-09-2008	16.30	21.10	18.70
11-10-2008	14.70	27.70	21.20
11-11-2008	14.70	21.30	18.00
11-12-2008	17.00	28.70	22.85
11-13-2008	15.60	28.30	21.95
11-14-2008	15.50	30.50	23.00
11-15-2008	13.60	31.30	22.45
11-16-2008	13.10	33.30	23.20
11-17-2008	13.70	30.30	22.00
11-18-2008	12.80	28.90	20.85
11-19-2008	14.20	23.30	18.75
11-20-2008	12.00	28.00	20.00

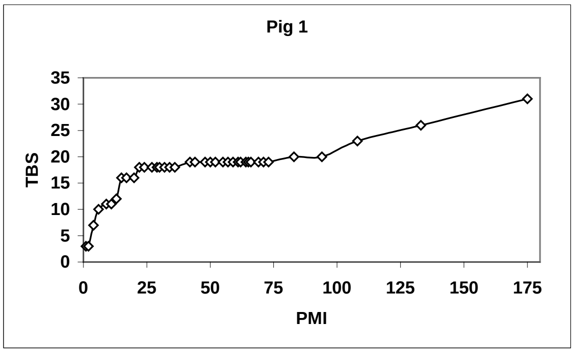
Date	Min Temp	Max Temp	Ave Temp
11-21-2008	11.90	28.20	20.05
11-22-2008	11.80	29.60	20.70
11-23-2008	13.40	32.70	23.05
11-24-2008	12.80	34.10	23.45
11-25-2008	14.30	33.80	24.05
11-26-2008	15.20	31.70	23.45
11-27-2008	14.60	32.30	23.45
11-28-2008	14.40	32.50	23.45
11-29-2008	14.30	33.50	23.90
11-30-2008	14.50	35.70	25.10
12-01-2008	14.40	29.50	21.95
12-02-2008	13.40	36.00	24.70
12-03-2008	16.40	37.20	26.80
12-04-2008	12.70	31.60	22.15
12-05-2008	17.10	31.90	24.50
12-06-2008	13.10	31.10	22.10
12-07-2008	13.90	31.90	22.90
12-08-2008	16.60	32.80	24.70
12-09-2008	12.70	34.30	23.50
12-10-2008	13.40	34.90	24.15
12-11-2008	11.50	33.40	22.45
12-12-2008	16.00	33.50	24.75
12-13-2008	14.50	33.60	24.05
12-14-2008	12.30	31.20	21.75
12-15-2008	15.40	28.00	21.70
12-16-2008	13.70	25.80	19.75
12-17-2008	11.80	32.50	22.15
12-18-2008	11.20	31.70	21.45
12-19-2008	11.40	33.50	22.45
12-20-2008	11.80	36.20	24.00
12-21-2008	12.80	34.80	23.80
12-22-2008	13.00	34.90	23.95
12-23-2008	14.70	35.30	25.00
12-24-2008	14.90	28.80	21.85
12-25-2008	14.70	33.00	23.85
12-26-2008	13.50	31.30	22.40
12-27-2008	14.70	31.20	22.95
12-28-2008	14.90	26.50	20.70
12-29-2008	17.30	34.00	25.65
12-30-2008	14.70	34.90	24.80
12-31-2008	11.90	35.40	23.65
01-01-2009	14.00	31.00	22.50
01-02-2009	13.70	34.10	23.90
01-03-2009	14.00	33.80	23.90
01-04-2009	12.80	36.30	24.55
01-05-2009	12.30	33.20	22.75
01-06-2009	12.70	35.00	23.85
01-07-2009	14.20	38.60	26.40
01-08-2009	17.10	35.40	26.25
01-09-2009	15.20	34.00	24.60
01-10-2009	17.40	26.80	22.10
01-11-2009	17.10	30.70	23.90
01-12-2009	16.00	25.20	20.60

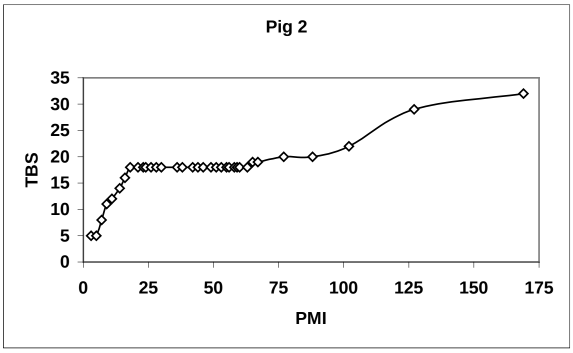
Date	Min Temp	Max Temp	Ave Temp
01-13-2009	15.20	30.80	23.00
01-14-2009	16.50	33.00	24.75
01-15-2009	15.30	32.60	23.95
01-16-2009	18.2	30.70	24.4
01-17-2009	18.4	32.20	25.3
01-18-2009	18.5	31.20	24.9
01-19-2009	18.6	30.20	24.4
01-20-1009	16.4	28.50	22.4
01-21-2009	17.4	28.70	23.1
01-22-2009	15.3	24.90	20.1
01-23-2009	15.4	28.60	22
01-24-2009	15.4	29.10	22.3
01-25-2009	15.3	31.80	23.55
01-26-2009	15.1	31.00	23.05
01-27-2009	14	31.70	22.85
01-28-2009	16.5	26.70	21.60
01-29-2009	16.6	24.50	20.55
01-30-2009	14.5	24.30	19.40
01-31-2009	15.4	33.10	24.25
02-01-2009	15.6	32.90	24.25
02-02-2009	14.9	29.60	22.25
02-03-2009	13.7	34.10	23.90
02-04-2009	15.9	26.50	21.20
02-05-2009	13.9	24.30	19.10
02-06-2009	11.8	29.20	20.50
02-07-2009	8.1	31.50	19.80
02-08-2009	10.4	34.80	22.60
02-09-2009	13	32.40	22.70
02-10-2009	15.2	32.80	24.00
02-11-2009	14.7	28.20	21.45
02-12-2009	11.9	26.00	18.95
02-13-2009	11.6	31.10	21.35
02-14-2009	14.3	28.40	21.4
02-15-2009	15.3	29.10	22.2
02-16-2009	15.4	30.30	22.9
02-17-2009	18.2	30.10	24.1
02-18-2009	18.6	29.60	24.1
02-19-2009	17.0	30.60	23.8
02-20-2009	18.3	30.70	24.5
02-21-2009	17.1	30.80	23.9
02-22-2009	15.4	30.50	22.9
02-23-2009	14.3	26.70	20.50
02-24-2009	14.3	23.70	19.00
02-25-2009	13.8	31.20	22.50
02-26-2009	13.5	33.60	23.55
02-27-2009	16.9	34.00	25.45
02-28-2009	16.1	31.20	23.65
03-01-2009	13.1	27.20	20.15
03-02-2009	11.9	31.00	21.45
03-03-2009	12.9	33.70	23.30
03-04-2009	12.7	31.40	22.05
03-05-2009	11.2	27.20	19.20
03-06-2009	8.5	30.40	19.45

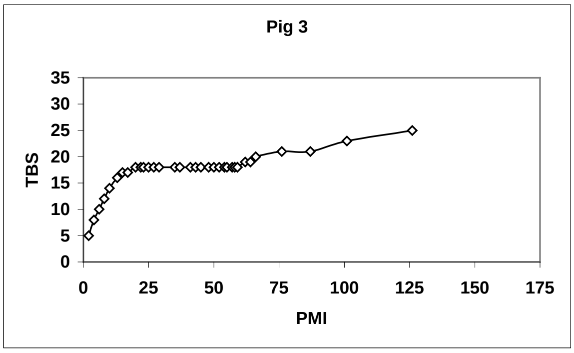
Date	Min Temp	Max Temp	Ave Temp
03-07-2009	9	33.10	21.05
03-08-2009	9.4	34.30	21.85
03-09-2009	11.4	30.40	20.90
03-10-2009	15	28.40	21.70
03-11-2009	14	29.60	21.80
03-12-2009	10.9	33.40	22.15
03-13-2009	11	31.60	21.30
03-14-2009	13.6	30.10	21.85
03-15-2009	12.8	26.90	19.85
03-16-2009	10.4	33.60	22.00
03-17-2009	11.7	32.80	22.25
03-18-2009	14.3	25.00	19.6
03-19-2009	13.5	23.90	18.7
03-20-2009	13.2	24.90	19.1
03-21-2009	11.1	25.80	18.4
03-22-2009	12.2	26.50	19.4
03-23-2009	11.1	28.00	19.6
03-24-2009	12.1	27.60	19.9
03-25-2009	12.0	28.10	20.1
03-26-2009	13.2	30.30	21.8
03-27-2009	15.2	28.30	21.8
03-28-2009	11.1	31.10	21.1
03-29-2009	12.2	29.00	20.6
03-30-2009	14.3	27.60	20.9
03-31-2009	13.2	28.60	20.9
04-01-2009	15.4	26.90	21.1
04-02-2009	12.2	28.10	20.1

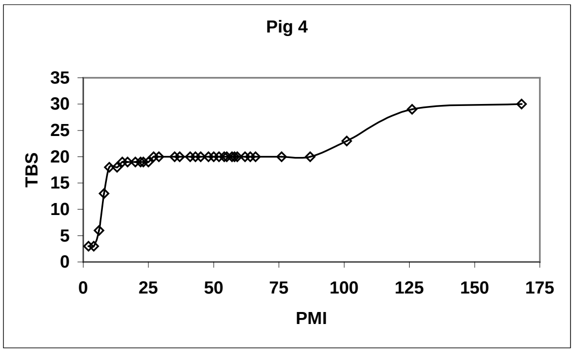
APPENDIX B: Scatter plots for individual pigs.

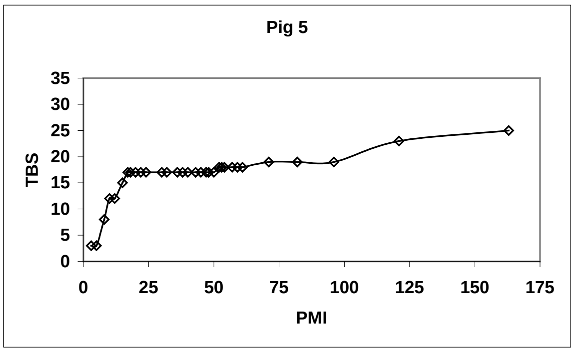
Appendix B.1: Scatter plots of TBS vs. PMI (in calendar days) for winter samples

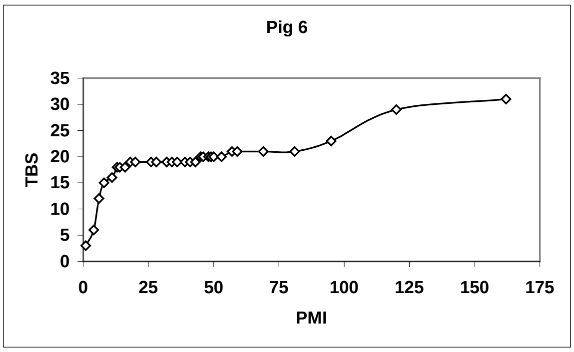


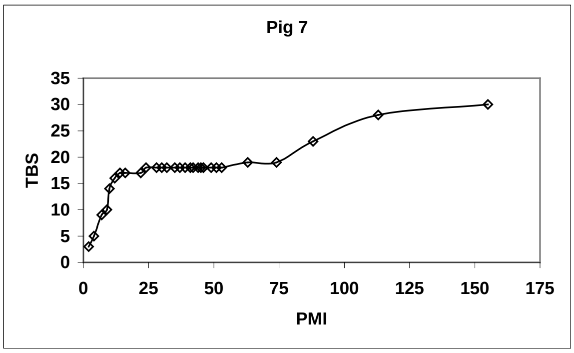


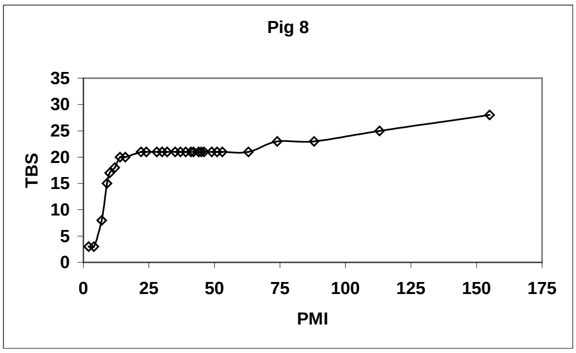




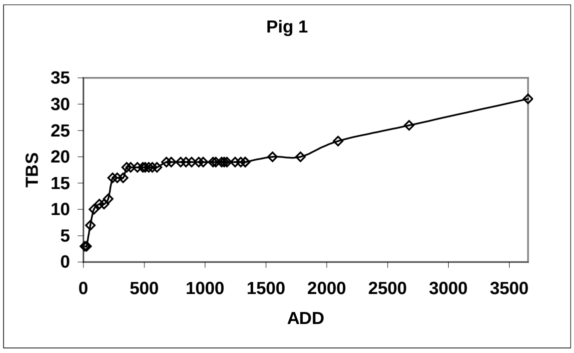


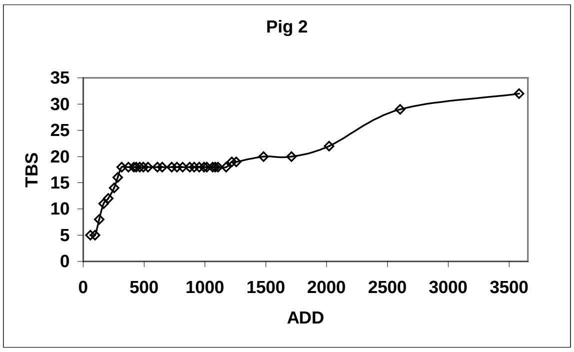


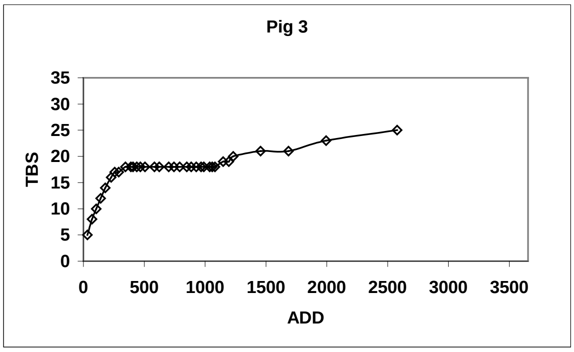


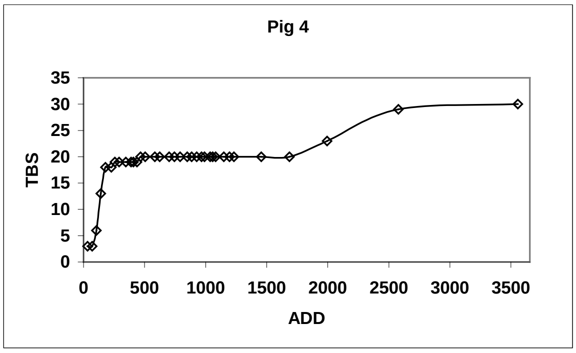


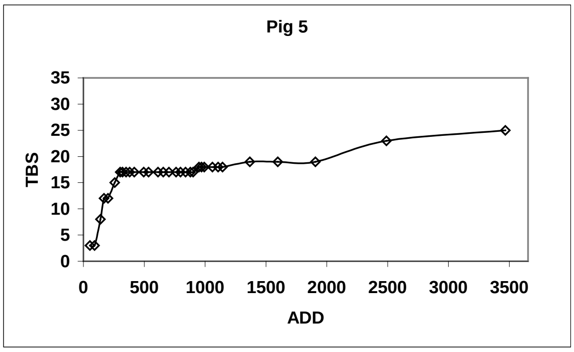
Appendix B.2: Scatter plots of TBS vs. ADD for winter samples

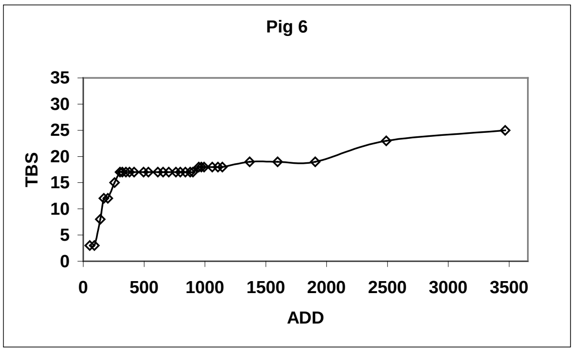


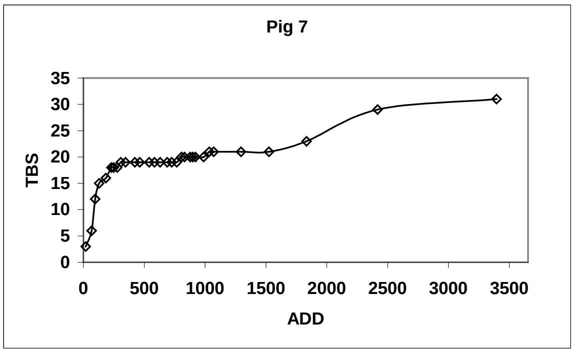


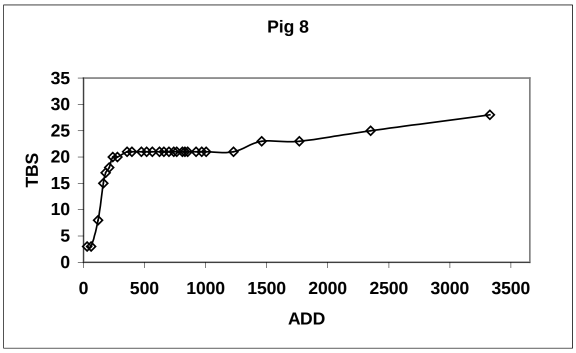




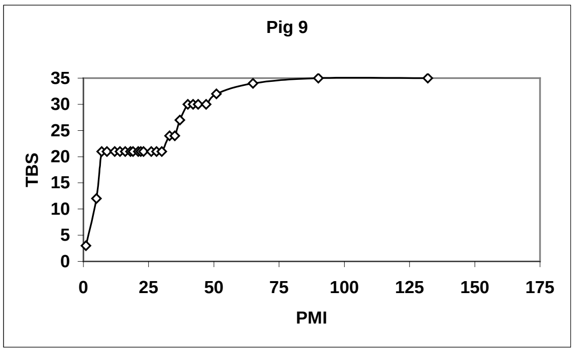


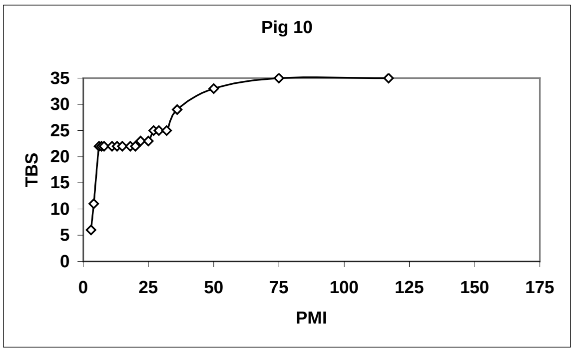


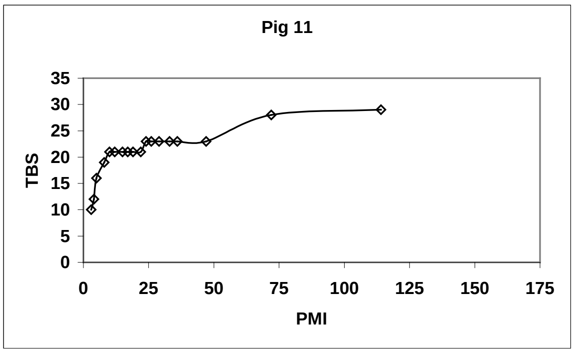


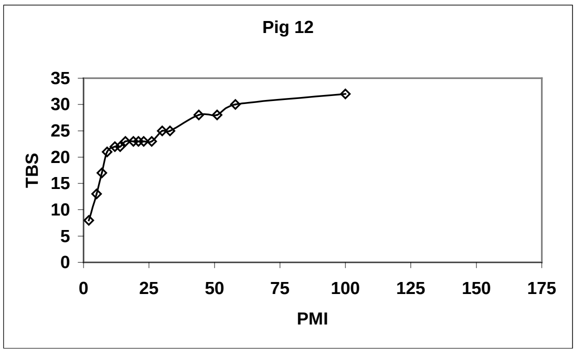


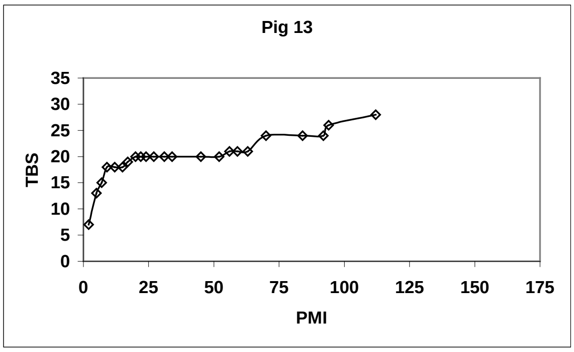
Appendix B.3: Scatter plots of TBS vs. PMI (in calendar days) for summer samples

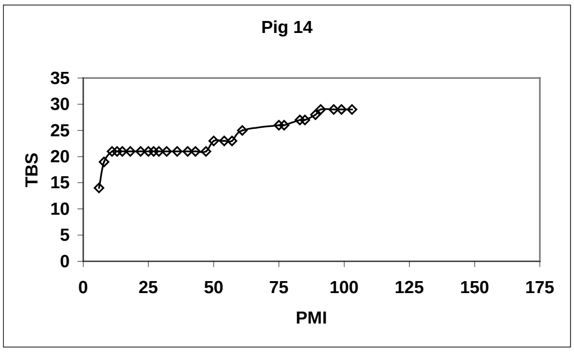


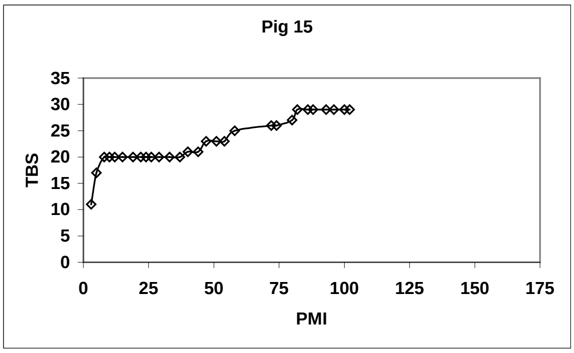


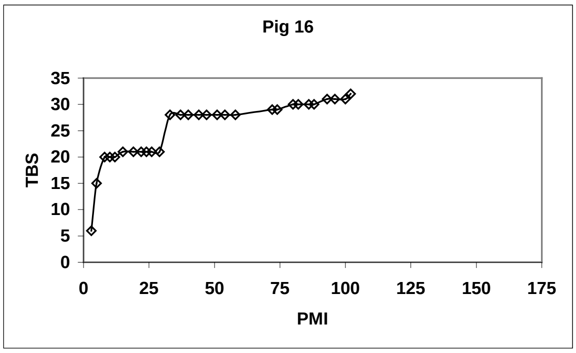


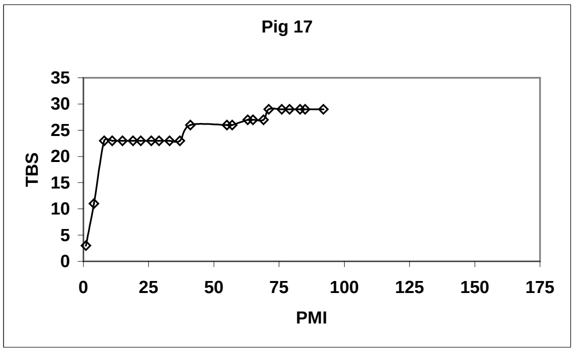




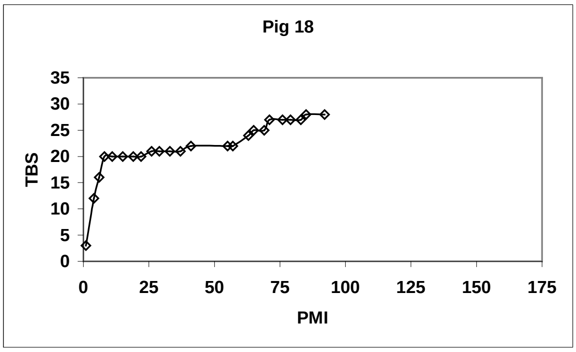




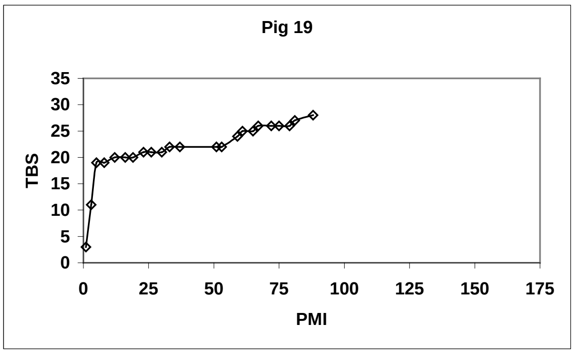




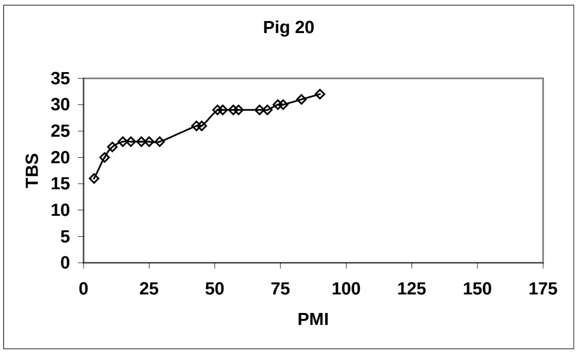
Pig 17
TBS
PMI



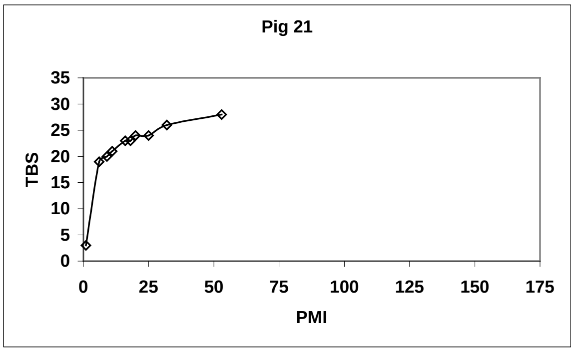
Pig 18
TBS
PMI



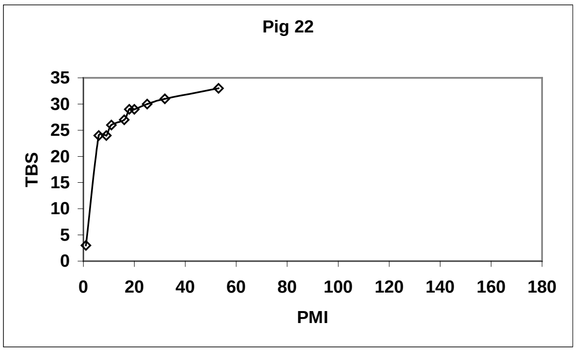
Pig 19
TBS
PMI



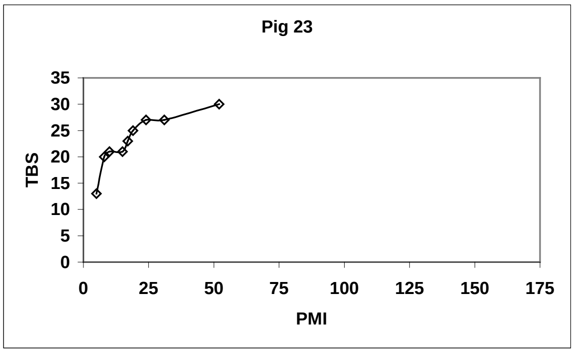
Pig 20
TBS
PMI



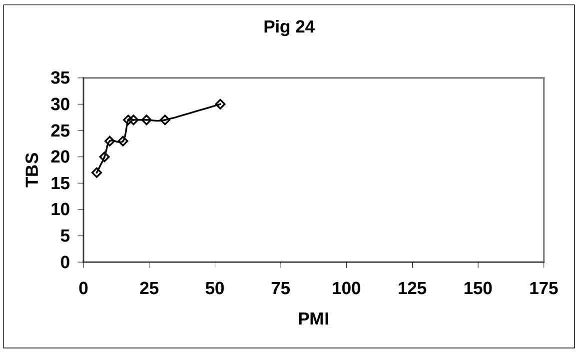
Pig 21
TBS
PMI



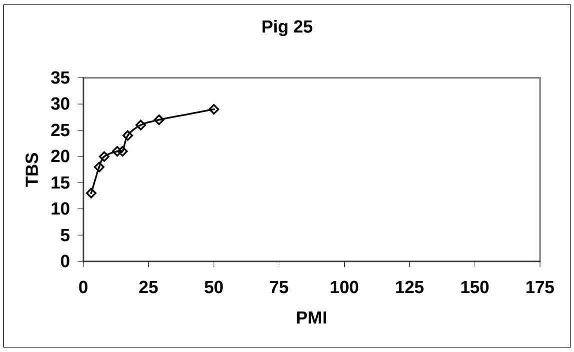
Pig 22
TBS
PMI



Pig 23
TBS
PMI



Pig 24
TBS
PMI


Pig 25
TBS
PMI
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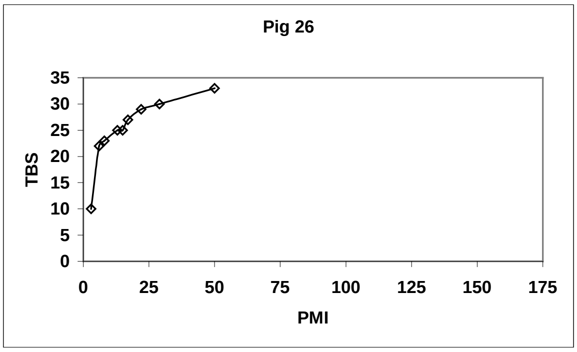
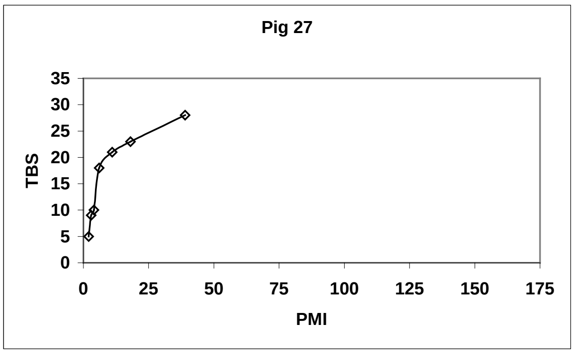
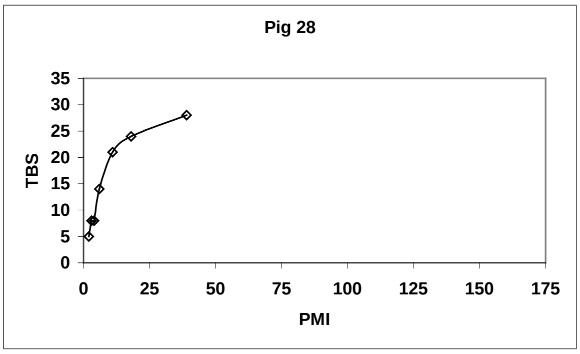
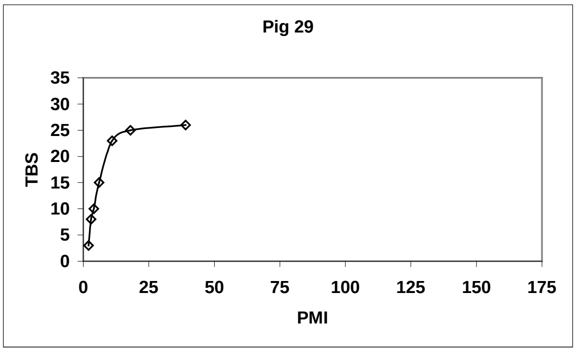
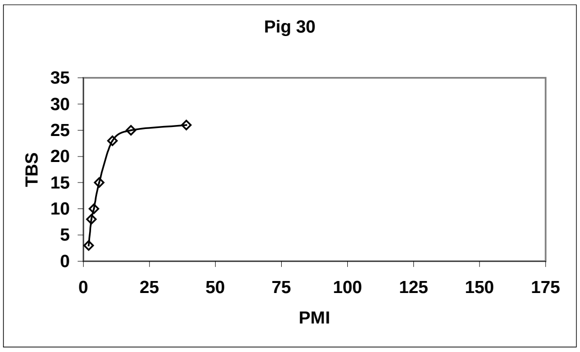
5
10
15
20
25
30
35
0
25
50
75
100
125
150
175


Pig 26
TBS
PMI
0
5
10
15
20
25
30
35
0
25
50
75
100
125
150
175

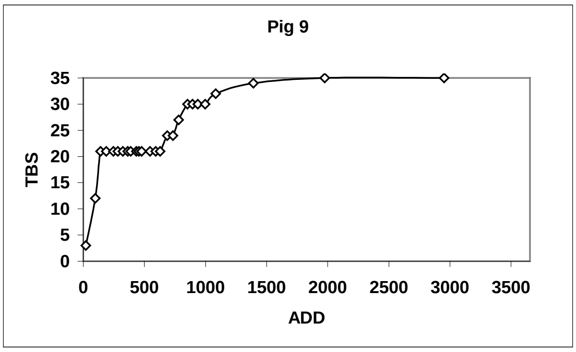

Pig 27
TBS
PMI
0
5
10
15
20
25
30
35
0
25
50
75
100
125
150
175

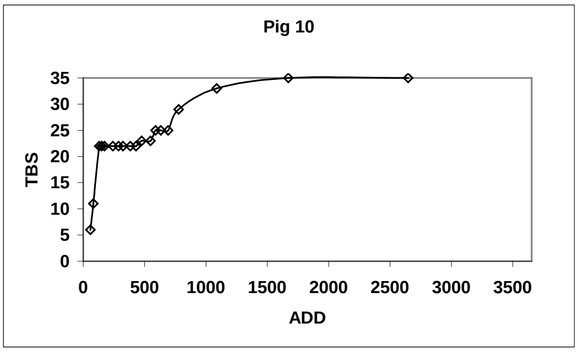

Pig 28
TBS
PMI
0
5
10
15
20
25
30
35
0
25
50
75
100
125
150
175

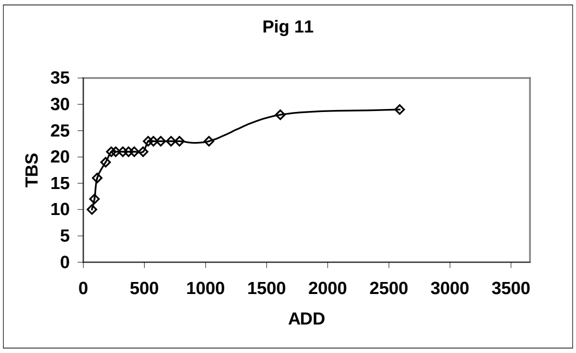

Pig 29
TBS
PMI
0
5
10
15
20
25
30
35
0
25
50
75
100
125
150
175

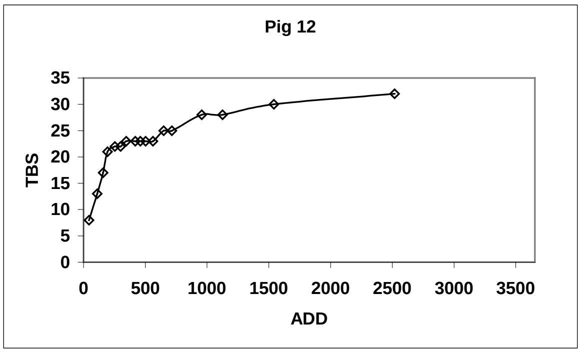

Pig 30
TBS
PMI
0
5
10
15
20
25
30
35
0
25
50
75
100
125
150
175

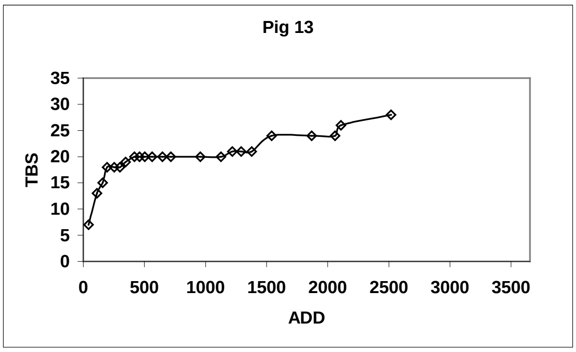
Appendix B.4: Scatter plots of TBS vs. ADD for summer samples

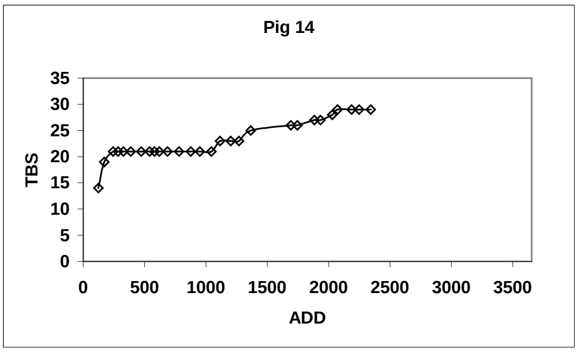


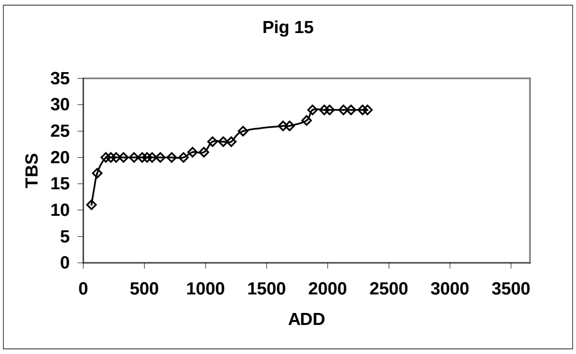


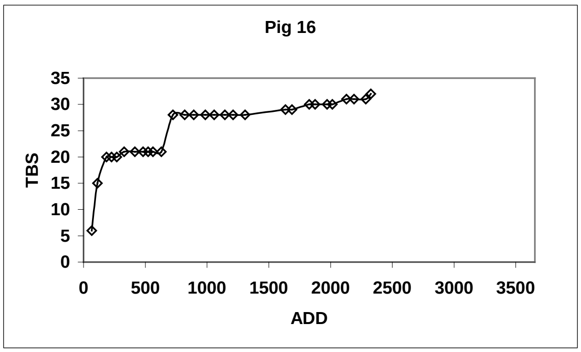


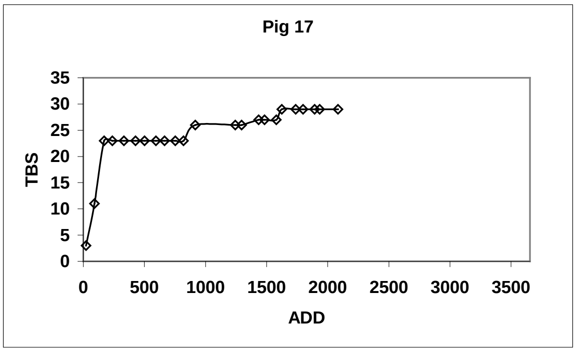


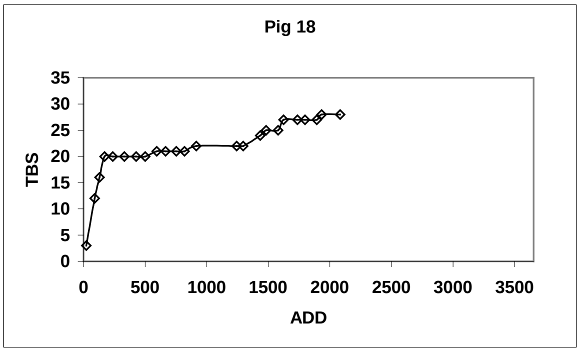


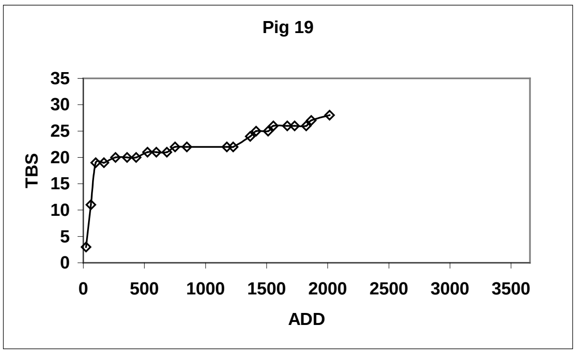


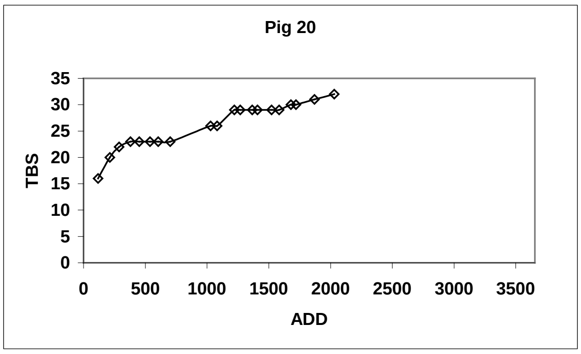


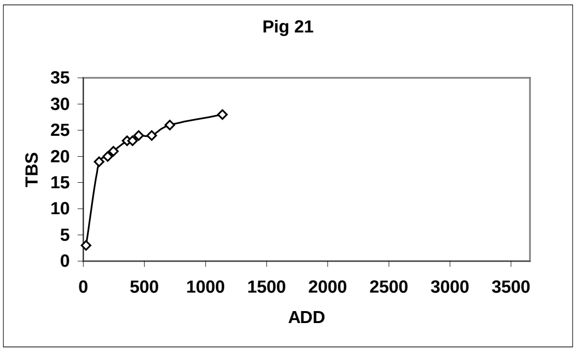


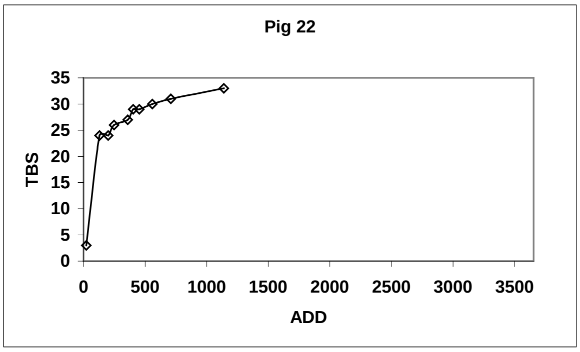

Pig 17
TBS
ADD

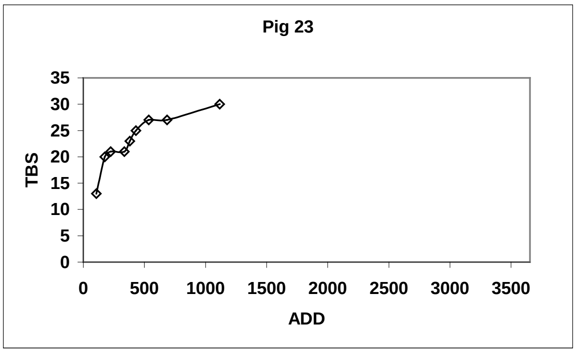

Pig 18
TBS
ADD

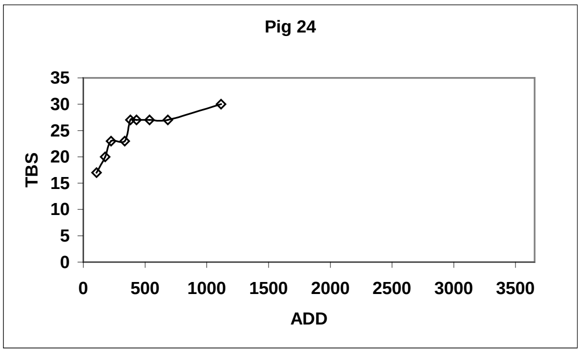

Pig 19
TBS
ADD

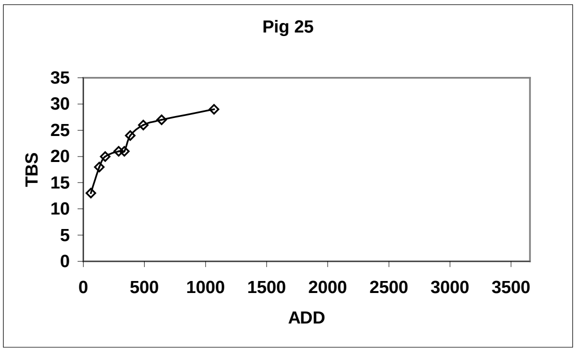

Pig 20
TBS
ADD

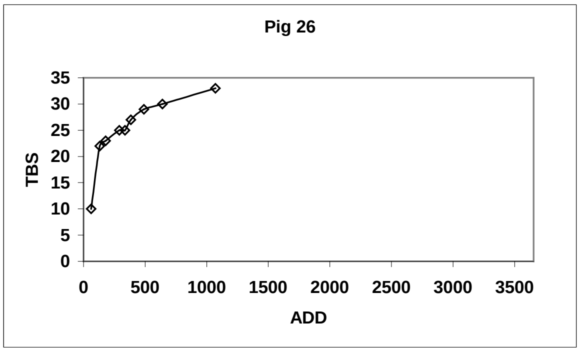

Pig 21
TBS
ADD


Pig 22
TBS
ADD


Pig 23
TBS
ADD


Pig 24
TBS
ADD


Pig 25
TBS
ADD
0 5 10 15 20 25 30 35
0 500 1000 1500 2000 2500 3000 3500


Pig 26
TBS
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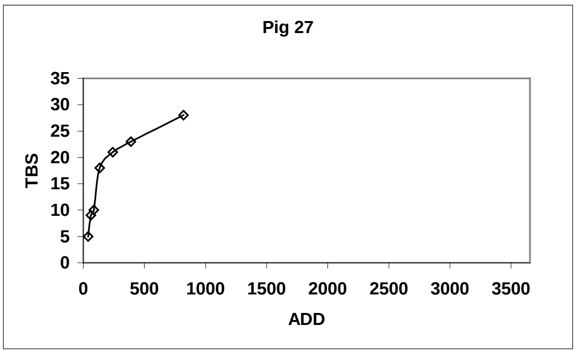
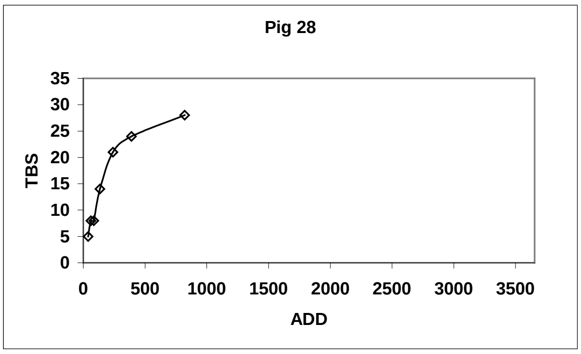
0 500 1000 1500 2000 2500 3000 3500


Pig 27
TBS
ADD
0 5 10 15 20 25 30 35
0 500 1000 1500 2000 2500 3000 3500


Pig 28
TBS
ADD
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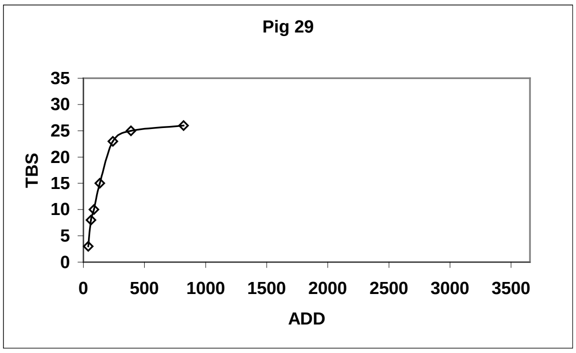
0 500 1000 1500 2000 2500 3000 3500


Pig 29
TBS
ADD
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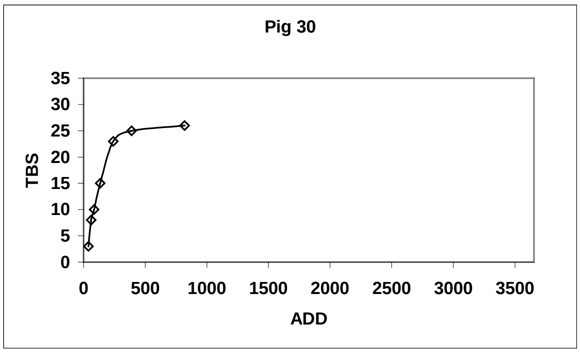
0 500 1000 1500 2000 2500 3000 3500


Pig 30
TBS
ADD
0 5 10 15 20 25 30 35
0 500 1000 1500 2000 2500 3000 3500

APPENDIX C: Data for the Post-mortem Interval value, head and neck score, trunk score, limbs score, Total Body Score value, average temperature, Accumulated Degree-Days value, logarithmic Post-mortem Interval value and logarithmic Accumulated Degree-Days value for individual pigs.

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
1	Winter	101	1	1	1	1	3	12.7	12.7	0.00	1.10
1	Winter	102	2	1	1	1	3	14	26.7	0.30	1.43
1	Winter	103	4	3	3	1	7	15.3	56.7	0.60	1.75
1	Winter	104	6	3	4	3	10	13.4	86	0.78	1.93
1	Winter	105	9	4	4	3	11	17.6	131.7	0.95	2.12
1	Winter	106	11	4	4	3	11	18.8	168.9	1.04	2.23
1	Winter	107	13	4	4	4	12	16.9	203.6	1.11	2.31
1	Winter	108	15	6	5	5	16	17.8	240	1.18	2.38
1	Winter	109	17	6	5	5	16	19.6	278.5	1.23	2.44
1	Winter	110	20	6	5	5	16	13.8	326.4	1.30	2.51
1	Winter	111	22	7	6	5	18	15.6	355.9	1.34	2.55
1	Winter	112	24	7	6	5	18	16.65	389.05	1.38	2.59
1	Winter	113	27	7	6	5	18	21.3	444.5	1.43	2.65
1	Winter	114	29	7	6	5	18	21.25	488.55	1.46	2.69
1	Winter	115	30	7	6	5	18	18.6	507.15	1.48	2.71
1	Winter	116	32	7	6	5	18	14.55	537.05	1.51	2.73
1	Winter	117	34	7	6	5	18	15.05	566.2	1.53	2.75
1	Winter	118	36	7	6	5	18	19.25	603.95	1.56	2.78
1	Winter	119	42	7	6	6	19	18.45	682.85	1.62	2.83
1	Winter	120	44	7	6	6	19	20.1	721.95	1.64	2.86
1	Winter	121	48	7	6	6	19	19.4	800	1.68	2.90
1	Winter	122	50	7	6	6	19	23.1	842.75	1.70	2.93
1	Winter	123	52	7	6	6	19	23.25	889.8	1.72	2.95
1	Winter	124	55	7	6	6	19	19.2	947.75	1.74	2.98

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
1	Winter	125	57	7	6	6	19	19.8	984.75	1.76	2.99
1	Winter	126	59	7	6	6	19	19.55	1065.25	1.77	3.03
1	Winter	127	61	7	6	6	19	20.35	1088.7	1.79	3.04
1	Winter	128	62	7	6	6	19	23.45	1135.9	1.79	3.06
1	Winter	129	64	7	6	6	19	22.4	1156.55	1.81	3.06
1	Winter	130	65	7	6	6	19	20.65	1179.55	1.81	3.07
1	Winter	131	66	7	6	6	19	23	1247.2	1.82	3.10
1	Winter	132	69	7	6	6	19	22.4	1293.9	1.84	3.11
1	Winter	133	71	7	6	6	19	24.2	1329.75	1.85	3.12
1	Winter	134	73	7	6	6	19	18.2	1329.75	1.86	3.12
1	Winter	135	83	8	6	6	20	25.25	1554.25	1.92	3.19
1	Winter	136	94	8	6	6	20	23	1784.2	1.97	3.25
1	Winter	137	108	8	7	8	23	23.45	2093.1	2.03	3.32
1	Winter	138	133	10	8	8	26	25	2676.8	2.12	3.43
1	Winter	139	175	12	10	9	31	23.9	3654.2	2.24	3.56
2	Winter	201	3	1	3	1	5	17.6	59.1	0.48	1.77
2	Winter	202	5	1	3	1	5	18.8	96.3	0.70	1.98
2	Winter	203	7	3	4	1	8	16.9	131	0.85	2.12
2	Winter	204	9	4	4	3	11	17.8	167.4	0.95	2.22
2	Winter	205	11	4	4	4	12	19.6	205.9	1.04	2.31
2	Winter	206	14	6	4	4	14	13.8	253.8	1.15	2.40
2	Winter	207	16	7	5	4	16	15.6	283.3	1.20	2.45
2	Winter	208	18	7	6	5	18	16.65	316.45	1.26	2.50
2	Winter	209	21	7	6	5	18	21.3	371.9	1.32	2.57
2	Winter	210	23	7	6	5	18	21.25	415.95	1.36	2.62
2	Winter	211	24	7	6	5	18	18.6	434.55	1.38	2.64
2	Winter	212	26	7	6	5	18	14.55	464.45	1.41	2.67
2	Winter	213	28	7	6	5	18	15.05	493.6	1.45	2.69
2	Winter	214	30	7	6	5	18	19.25	531.35	1.48	2.73
2	Winter	215	36	7	6	5	18	18.45	610.25	1.56	2.79

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
2	Winter	216	38	7	6	5	18	20.1	649.35	1.58	2.81
2	Winter	217	42	7	6	5	18	19.4	727.4	1.62	2.86
2	Winter	218	44	7	6	5	18	23.1	770.15	1.64	2.89
2	Winter	219	46	7	6	5	18	23.25	817.2	1.66	2.91
2	Winter	220	49	7	6	5	18	19.2	875.15	1.69	2.94
2	Winter	221	51	7	6	5	18	19.8	912.15	1.71	2.96
2	Winter	222	53	7	6	5	18	19.55	953.25	1.72	2.98
2	Winter	223	55	7	6	5	18	20.35	992.65	1.74	3.00
2	Winter	224	56	7	6	5	18	23.45	1016.1	1.75	3.01
2	Winter	225	58	7	6	5	18	22.4	1063.3	1.76	3.03
2	Winter	226	59	7	6	5	18	20.65	1083.95	1.77	3.04
2	Winter	227	60	7	6	5	18	23	1106.95	1.78	3.04
2	Winter	228	63	7	6	5	18	22.4	1174.6	1.80	3.07
2	Winter	229	65	7	7	5	19	24.2	1221.3	1.81	3.09
2	Winter	230	67	7	7	5	19	18.2	1257.15	1.83	3.10
2	Winter	231	77	7	7	6	20	25.25	1481.65	1.89	3.17
2	Winter	232	88	7	7	6	20	23	1711.6	1.94	3.23
2	Winter	233	102	7	7	8	22	23.45	2020.5	2.01	3.31
2	Winter	334	127	11	10	8	29	25	2604.2	2.10	3.42
2	Winter	235	169	13	10	9	32	23.9	3581.6	2.23	3.55
3	Winter	301	2	1	3	1	5	17.6	32.9	0.30	1.52
3	Winter	302	4	1	4	3	8	18.8	70.1	0.60	1.85
3	Winter	303	6	3	4	3	10	16.9	104.8	0.78	2.02
3	Winter	304	8	4	4	4	12	17.8	141.2	0.90	2.15
3	Winter	305	10	4	5	5	14	19.6	179.7	1.00	2.25
3	Winter	306	13	5	6	5	16	13.8	227.6	1.11	2.36
3	Winter	307	15	6	6	5	17	15.6	257.1	1.18	2.41
3	Winter	308	17	6	6	5	17	16.65	290.25	1.23	2.46
3	Winter	309	20	7	6	5	18	21.3	345.7	1.30	2.54
3	Winter	310	22	7	6	5	18	21.25	389.75	1.34	2.59

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
3	Winter	311	23	7	6	5	18	18.6	408.35	1.36	2.61
3	Winter	312	25	7	6	5	18	14.55	438.25	1.40	2.64
3	Winter	313	27	7	6	5	18	15.05	467.4	1.43	2.67
3	Winter	314	29	7	6	5	18	19.25	505.15	1.46	2.70
3	Winter	315	35	7	6	5	18	18.45	584.05	1.54	2.77
3	Winter	316	37	7	6	5	18	20.1	623.15	1.57	2.79
3	Winter	317	41	7	6	5	18	19.4	701.2	1.61	2.85
3	Winter	318	43	7	6	5	18	23.1	743.95	1.63	2.87
3	Winter	319	45	7	6	5	18	23.25	791	1.65	2.90
3	Winter	320	48	7	6	5	18	19.2	848.95	1.68	2.93
3	Winter	321	50	7	6	5	18	19.8	885.95	1.70	2.95
3	Winter	322	52	7	6	5	18	19.55	927.05	1.72	2.97
3	Winter	323	54	7	6	5	18	20.35	966.45	1.73	2.99
3	Winter	324	55	7	6	5	18	23.45	989.9	1.74	3.00
3	Winter	325	57	7	6	5	18	22.4	1037.1	1.76	3.02
3	Winter	326	58	7	6	5	18	20.65	1057.75	1.76	3.02
3	Winter	327	59	7	6	5	18	23	1080.75	1.77	3.03
3	Winter	328	62	8	6	5	19	22.4	1148.4	1.79	3.06
3	Winter	329	64	8	6	5	19	24.2	1195.1	1.81	3.08
3	Winter	330	66	8	6	6	20	18.2	1230.95	1.82	3.09
3	Winter	331	76	8	7	6	21	25.25	1455.45	1.88	3.16
3	Winter	332	87	8	7	6	21	23	1685.4	1.94	3.23
3	Winter	333	101	8	7	8	23	23.45	1994.3	2.00	3.30
3	Winter	334	126	9	8	8	25	25	2578	2.10	3.41
4	Winter	401	2	1	1	1	3	17.6	32.9	0.30	1.52
4	Winter	402	4	1	1	1	3	18.8	70.1	0.60	1.85
4	Winter	403	6	2	3	1	6	16.9	104.8	0.78	2.02
4	Winter	404	8	4	5	4	13	17.8	141.2	0.90	2.15
4	Winter	405	10	7	6	5	18	19.6	179.7	1.00	2.25
4	Winter	406	13	7	6	5	18	13.8	227.6	1.11	2.36

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
4	Winter	407	15	8	6	5	19	15.6	257.1	1.18	2.41
4	Winter	408	17	8	6	5	19	16.65	290.25	1.23	2.46
4	Winter	409	20	8	6	5	19	21.3	345.7	1.30	2.54
4	Winter	410	22	8	6	5	19	21.25	389.75	1.34	2.59
4	Winter	411	23	8	6	5	19	18.6	408.35	1.36	2.61
4	Winter	412	25	8	6	5	19	14.55	438.25	1.40	2.64
4	Winter	413	27	8	6	6	20	15.05	467.4	1.43	2.67
4	Winter	414	29	8	6	6	20	19.25	505.15	1.46	2.70
4	Winter	415	35	8	6	6	20	18.45	584.05	1.54	2.77
4	Winter	416	37	8	6	6	20	20.1	623.15	1.57	2.79
4	Winter	417	41	8	6	6	20	19.4	701.2	1.61	2.85
4	Winter	418	43	8	6	6	20	23.1	743.95	1.63	2.87
4	Winter	419	45	8	6	6	20	23.25	791	1.65	2.90
4	Winter	420	48	8	6	6	20	19.2	848.95	1.68	2.93
4	Winter	421	50	8	6	6	20	19.8	885.95	1.70	2.95
4	Winter	422	52	8	6	6	20	19.55	927.05	1.72	2.97
4	Winter	423	54	8	6	6	20	20.35	966.45	1.73	2.99
4	Winter	424	55	8	6	6	20	23.45	989.9	1.74	3.00
4	Winter	425	57	8	6	6	20	22.4	1037.1	1.76	3.02
4	Winter	426	58	8	6	6	20	20.65	1057.75	1.76	3.02
4	Winter	427	59	8	6	6	20	23	1080.75	1.77	3.03
4	Winter	428	62	8	6	6	20	22.4	1148.4	1.79	3.06
4	Winter	429	64	8	6	6	20	24.2	1195.1	1.81	3.08
4	Winter	430	66	8	6	6	20	18.2	1230.95	1.82	3.09
4	Winter	431	76	8	6	6	20	25.25	1455.45	1.88	3.16
4	Winter	432	87	8	6	6	20	23	1685.4	1.94	3.23
4	Winter	433	101	8	7	8	23	23.45	1994.3	2.00	3.30
4	Winter	434	126	11	10	8	29	25	2578	2.10	3.41
4	Winter	435	168	11	10	9	30	23.9	3555.4	2.23	3.55
5	Winter	501	3	1	1	1	3	17.8	53.3	0.48	1.73

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
5	Winter	502	5	1	1	1	3	19.6	91.8	0.70	1.96
5	Winter	503	8	2	4	2	8	13.8	139.7	0.90	2.15
5	Winter	504	10	5	4	3	12	15.6	169.2	1.00	2.23
5	Winter	505	12	5	4	3	12	16.65	202.35	1.08	2.31
5	Winter	506	15	6	4	5	15	21.3	257.8	1.18	2.41
5	Winter	507	17	7	5	5	17	21.25	301.85	1.23	2.48
5	Winter	508	18	7	5	5	17	18.6	320.45	1.26	2.51
5	Winter	509	20	7	5	5	17	14.55	350.35	1.30	2.54
5	Winter	510	22	7	5	5	17	15.05	379.5	1.34	2.58
5	Winter	511	24	7	5	5	17	19.25	417.25	1.38	2.62
5	Winter	512	30	7	5	5	17	18.45	496.15	1.48	2.70
5	Winter	513	32	7	5	5	17	20.1	535.25	1.51	2.73
5	Winter	514	36	7	5	5	17	19.4	613.3	1.56	2.79
5	Winter	515	38	7	5	5	17	23.1	656.05	1.58	2.82
5	Winter	516	40	7	5	5	17	23.25	703.1	1.60	2.85
5	Winter	517	43	7	5	5	17	19.2	761.05	1.63	2.88
5	Winter	518	45	7	5	5	17	19.8	798.05	1.65	2.90
5	Winter	519	47	7	5	5	17	19.55	839.15	1.67	2.92
5	Winter	520	48	7	5	5	17	20.35	878.55	1.68	2.94
5	Winter	521	50	7	5	5	17	23.45	902	1.70	2.96
5	Winter	522	52	7	6	5	18	22.4	949.2	1.72	2.98
5	Winter	523	53	7	6	5	18	20.65	969.85	1.72	2.99
5	Winter	524	54	7	6	5	18	23	992.85	1.73	3.00
5	Winter	525	57	7	6	5	18	22.4	1060.5	1.76	3.03
5	Winter	526	59	7	6	5	18	24.2	1107.2	1.77	3.04
5	Winter	527	61	7	6	5	18	18.2	1143.05	1.79	3.06
5	Winter	528	71	7	6	6	19	25.25	1367.55	1.85	3.14
5	Winter	529	82	7	6	6	19	23	1597.5	1.91	3.20
5	Winter	530	96	7	6	6	19	23.45	1906.4	1.98	3.28
5	Winter	531	121	8	7	8	23	25	2490.1	2.08	3.40

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
5	Winter	532	163	9	8	8	25	23.9	3467.5	2.21	3.54
6	Winter	601	1	1	1	1	3	19.6	19.6	0.00	1.29
6	Winter	602	4	1	4	1	6	13.8	67.5	0.60	1.83
6	Winter	603	6	3	5	4	12	15.6	97	0.78	1.99
6	Winter	604	8	4	6	5	15	16.65	130.15	0.90	2.11
6	Winter	605	11	5	6	5	16	21.3	185.6	1.04	2.27
6	Winter	606	13	7	6	5	18	21.25	229.65	1.11	2.36
6	Winter	607	14	7	6	5	18	18.6	248.25	1.15	2.39
6	Winter	608	16	7	6	5	18	14.55	278.15	1.20	2.44
6	Winter	609	18	7	7	5	19	15.05	307.3	1.26	2.49
6	Winter	610	20	7	7	5	19	19.25	345.05	1.30	2.54
6	Winter	611	26	7	7	5	19	18.45	423.95	1.41	2.63
6	Winter	612	28	7	7	5	19	20.1	463.05	1.45	2.67
6	Winter	613	32	7	7	5	19	19.4	541.1	1.51	2.73
6	Winter	614	34	7	7	5	19	23.1	583.85	1.53	2.77
6	Winter	615	36	7	7	5	19	23.25	630.9	1.56	2.80
6	Winter	616	39	7	7	5	19	19.2	688.85	1.59	2.84
6	Winter	617	41	7	7	5	19	19.8	725.85	1.61	2.86
6	Winter	618	43	7	7	5	19	19.55	766.95	1.63	2.88
6	Winter	619	45	7	7	6	20	20.35	806.35	1.65	2.91
6	Winter	620	46	7	7	6	20	23.45	829.8	1.66	2.92
6	Winter	621	48	7	7	6	20	22.4	877	1.68	2.94
6	Winter	622	49	7	7	6	20	20.65	897.65	1.69	2.95
6	Winter	623	50	7	7	6	20	23	920.65	1.70	2.96
6	Winter	624	53	7	7	6	20	22.4	988.3	1.72	2.99
6	Winter	625	57	8	7	6	21	24.2	1035	1.76	3.01
6	Winter	626	59	8	7	6	21	18.2	1070.85	1.77	3.03
6	Winter	627	69	8	7	6	21	25.25	1295.35	1.84	3.11
6	Winter	628	81	8	7	8	21	23	1525.3	1.91	3.18
6	Winter	629	95	8	7	8	23	23.45	1834.2	1.98	3.26

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
6	Winter	630	120	11	10	8	29	25	2417.9	2.08	3.38
6	Winter	631	162	12	10	9	31	23.9	3395.3	2.21	3.53
7	Winter	701	2	1	1	1	3	15.6	29.5	0.30	1.47
7	Winter	702	4	1	3	1	5	16.65	62.65	0.60	1.80
7	Winter	703	7	2	4	3	9	21.3	118.1	0.85	2.07
7	Winter	704	9	2	5	3	10	21.25	162.15	0.95	2.21
7	Winter	705	10	4	5	5	14	18.6	180.75	1.00	2.26
7	Winter	706	12	5	6	5	16	14.55	210.65	1.08	2.32
7	Winter	707	14	6	6	5	17	15.05	239.8	1.15	2.38
7	Winter	708	16	6	6	5	17	19.25	277.55	1.20	2.44
7	Winter	709	22	6	6	5	17	18.45	356.45	1.34	2.55
7	Winter	710	24	7	6	5	18	20.1	395.55	1.38	2.60
7	Winter	711	28	7	6	5	18	19.4	473.6	1.45	2.68
7	Winter	712	30	7	6	5	18	23.1	516.35	1.48	2.71
7	Winter	713	32	7	6	5	18	23.25	563.4	1.51	2.75
7	Winter	714	35	7	6	5	18	19.2	621.35	1.54	2.79
7	Winter	715	37	7	6	5	18	19.8	658.35	1.57	2.82
7	Winter	716	39	7	6	5	18	19.55	699.45	1.59	2.84
7	Winter	717	41	7	6	5	18	20.35	738.85	1.61	2.87
7	Winter	718	42	7	6	5	18	23.45	762.3	1.62	2.88
7	Winter	719	44	7	6	5	18	22.4	809.5	1.64	2.91
7	Winter	720	45	7	6	5	18	20.65	830.15	1.65	2.92
7	Winter	721	46	7	6	5	18	23	853.15	1.66	2.93
7	Winter	722	49	7	6	5	18	22.4	920.8	1.69	2.96
7	Winter	723	51	7	6	5	18	24.2	967.5	1.71	2.99
7	Winter	724	53	7	6	5	18	18.2	1003.35	1.72	3.00
7	Winter	725	63	7	6	6	19	25.25	1227.85	1.80	3.09
7	Winter	726	74	7	6	6	19	23	1457.8	1.87	3.16
7	Winter	727	88	9	6	8	23	23.45	1766.7	1.94	3.25
7	Winter	728	113	11	8	9	28	25	2350.4	2.05	3.37

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
7	Winter	729	155	12	9	9	30	23.9	3327.8	2.19	3.52
8	Winter	801	2	1	1	1	3	15.6	29.5	0.30	1.47
8	Winter	802	4	1	1	1	3	16.65	62.65	0.60	1.80
8	Winter	803	7	2	4	2	8	21.3	118.1	0.85	2.07
8	Winter	804	9	5	5	5	15	21.25	162.15	0.95	2.21
8	Winter	805	10	6	6	5	17	18.6	180.75	1.00	2.26
8	Winter	806	12	7	6	5	18	14.55	210.65	1.08	2.32
8	Winter	807	14	7	7	6	20	15.05	239.8	1.15	2.38
8	Winter	808	16	7	7	6	20	19.25	277.55	1.20	2.44
8	Winter	809	22	8	7	6	21	18.45	356.45	1.34	2.55
8	Winter	810	24	8	7	6	21	20.1	395.55	1.38	2.60
8	Winter	811	28	8	7	6	21	19.4	473.6	1.45	2.68
8	Winter	812	30	8	7	6	21	23.1	516.35	1.48	2.71
8	Winter	813	32	8	7	6	21	23.25	563.4	1.51	2.75
8	Winter	814	35	8	7	6	21	19.2	621.35	1.54	2.79
8	Winter	815	37	8	7	6	21	19.8	658.35	1.57	2.82
8	Winter	816	39	8	7	6	21	19.55	699.45	1.59	2.84
8	Winter	817	41	8	7	6	21	20.35	738.85	1.61	2.87
8	Winter	818	42	8	7	6	21	23.45	762.3	1.62	2.88
8	Winter	819	44	8	7	6	21	22.4	809.5	1.64	2.91
8	Winter	820	45	8	7	6	21	20.65	830.15	1.65	2.92
8	Winter	821	46	8	7	6	21	23	853.15	1.66	2.93
8	Winter	822	49	8	7	6	21	22.4	920.8	1.69	2.96
8	Winter	823	51	8	7	6	21	24.2	967.5	1.71	2.99
8	Winter	824	53	8	7	6	21	18.2	1003.35	1.72	3.00
8	Winter	825	63	8	7	6	21	25.25	1227.85	1.80	3.09
8	Winter	826	74	8	7	8	23	23	1457.8	1.87	3.16
8	Winter	827	88	8	7	8	23	23.45	1766.7	1.94	3.25
8	Winter	828	113	9	8	8	25	25	2350.4	2.05	3.37
8	Winter	829	155	10	9	9	28	23.9	3327.8	2.19	3.52

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
9	Summer	901	1	1	1	1	3	20.1	20.1	0.00	1.30
9	Summer	902	5	5	4	3	12	19.4	98.15	0.70	1.99
9	Summer	903	7	8	7	6	21	23.1	140.9	0.85	2.15
9	Summer	904	9	8	7	6	21	23.25	187.95	0.95	2.27
9	Summer	905	12	8	7	6	21	19.2	245.9	1.08	2.39
9	Summer	906	14	8	7	6	21	19.8	282.9	1.15	2.45
9	Summer	907	16	8	7	6	21	19.55	324	1.20	2.51
9	Summer	908	18	8	7	6	21	20.35	363.4	1.26	2.56
9	Summer	909	19	8	7	6	21	23.45	386.85	1.28	2.59
9	Summer	910	21	8	7	6	21	22.4	434.05	1.32	2.64
9	Summer	911	22	8	7	6	21	20.65	454.7	1.34	2.66
9	Summer	912	23	8	7	6	21	23	477.7	1.36	2.68
9	Summer	913	26	8	7	6	21	22.4	545.35	1.41	2.74
9	Summer	914	28	8	7	6	21	24.2	592.05	1.45	2.77
9	Summer	915	30	8	7	6	21	18.2	627.9	1.48	2.80
9	Summer	916	33	8	8	8	24	20.25	687.55	1.52	2.84
9	Summer	917	35	8	8	8	24	22.8	733.65	1.54	2.87
9	Summer	918	37	10	9	8	27	24.6	780.25	1.57	2.89
9	Summer	919	40	10	10	10	30	25.25	852.4	1.60	2.93
9	Summer	920	42	10	10	10	30	20.15	893.6	1.62	2.95
9	Summer	921	44	10	10	10	30	19.95	936.8	1.64	2.97
9	Summer	922	47	10	10	10	30	21.2	996.55	1.67	3.00
9	Summer	923	51	11	11	10	32	23	1082.35	1.71	3.03
9	Summer	924	65	13	11	10	34	23.45	1391.25	1.81	3.14
9	Summer	925	90	13	12	10	35	25	1974.95	1.95	3.30
9	Summer	926	132	13	12	10	35	23.9	2952.35	2.12	3.47
10	Summer	1001	3	2	3	1	6	20.35	58.95	0.48	1.77
10	Summer	1002	4	4	4	3	11	23.45	82.4	0.60	1.92
10	Summer	1003	6	9	7	6	22	22.4	129.6	0.78	2.11
10	Summer	1004	7	9	7	6	22	20.65	150.25	0.85	2.18

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
10	Summer	1005	8	9	7	6	22	23	173.25	0.90	2.24
10	Summer	1006	11	9	7	6	22	22.4	240.9	1.04	2.38
10	Summer	1007	13	9	7	6	22	24.2	287.6	1.11	2.46
10	Summer	1008	15	9	7	6	22	18.2	323.45	1.18	2.51
10	Summer	1009	18	9	7	6	22	20.25	383.1	1.26	2.58
10	Summer	1010	20	9	7	6	22	22.8	429.2	1.30	2.63
10	Summer	1011	22	10	7	6	23	24.6	475.8	1.34	2.68
10	Summer	1012	25	10	7	6	23	25.25	547.95	1.40	2.74
10	Summer	1013	27	10	7	8	25	20.15	589.15	1.43	2.77
10	Summer	1014	29	10	7	8	25	19.95	632.35	1.46	2.80
10	Summer	1015	32	10	7	8	25	21.2	692.1	1.51	2.84
10	Summer	1016	36	10	10	9	29	23	777.9	1.56	2.89
10	Summer	1017	50	13	10	10	33	23.45	1086.8	1.70	3.04
10	Summer	1018	75	13	12	10	35	25	1670.5	1.88	3.22
10	Summer	1019	117	13	12	10	35	23.9	2647.9	2.07	3.42
11	Summer	1101	3	3	4	3	10	22.4	70.65	0.48	1.85
11	Summer	1102	4	5	4	3	12	20.65	91.3	0.60	1.96
11	Summer	1103	5	6	5	5	16	23	114.3	0.70	2.06
11	Summer	1104	8	7	7	5	19	22.4	181.95	0.90	2.26
11	Summer	1105	10	8	7	6	21	24.2	228.65	1.00	2.36
11	Summer	1106	12	8	7	6	21	18.2	264.5	1.08	2.42
11	Summer	1107	15	8	7	6	21	20.25	324.15	1.18	2.51
11	Summer	1108	17	8	7	6	21	22.8	370.25	1.23	2.57
11	Summer	1109	19	8	7	6	21	24.6	416.85	1.28	2.62
11	Summer	1110	22	8	7	6	21	25.25	489	1.34	2.69
11	Summer	1111	24	8	7	8	23	20.15	530.2	1.38	2.72
11	Summer	1112	26	8	7	8	23	19.95	573.4	1.41	2.76
11	Summer	1113	29	8	7	8	23	21.2	633.15	1.46	2.80
11	Summer	1114	33	8	7	8	23	23	718.95	1.52	2.86
11	Summer	1115	36	8	7	8	23	22	786.6	1.56	2.90

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
11	Summer	1116	47	8	7	8	23	23.45	1027.85	1.67	3.01
11	Summer	1117	72	10	10	8	28	25	1611.55	1.86	3.21
11	Summer	1118	114	11	10	8	29	23.9	2588.95	2.06	3.41
12	Summer	1201	2	2	4	2	8	23	43.65	0.30	1.64
12	Summer	1202	5	6	4	3	13	22.4	111.3	0.70	2.05
12	Summer	1203	7	7	5	5	17	24.2	158	0.85	2.20
12	Summer	1204	9	10	6	5	21	18.2	193.85	0.95	2.29
12	Summer	1205	12	10	7	5	22	20.25	253.5	1.08	2.40
12	Summer	1206	14	10	7	5	22	22.8	299.6	1.15	2.48
12	Summer	1207	16	10	7	6	23	24.6	346.2	1.20	2.54
12	Summer	1208	19	10	7	6	23	25.25	418.35	1.28	2.62
12	Summer	1209	21	10	7	6	23	20.15	459.55	1.32	2.66
12	Summer	1210	23	10	7	6	23	19.95	502.75	1.36	2.70
12	Summer	1211	26	10	7	6	23	21.2	562.5	1.41	2.75
12	Summer	1212	30	10	7	8	25	23	648.3	1.48	2.81
12	Summer	1213	33	10	7	8	25	22	715.95	1.52	2.85
12	Summer	1214	44	13	7	8	28	23.45	957.2	1.64	2.98
12	Summer	1215	51	13	7	8	28	24.5	1126.3	1.71	3.05
12	Summer	1216	58	13	9	8	30	25	1540.9	1.76	3.19
12	Summer	1217	100	13	10	9	32	23.9	2518.3	2.00	3.40
13	Summer	1301	2	2	3	2	7	23	43.65	0.30	1.64
13	Summer	1302	5	6	4	3	13	22.4	111.3	0.70	2.05
13	Summer	1303	7	6	5	4	15	24.2	158	0.85	2.20
13	Summer	1304	9	7	6	5	18	18.2	193.85	0.95	2.29
13	Summer	1305	12	7	6	5	18	20.25	253.5	1.08	2.40
13	Summer	1306	15	7	6	5	18	22.8	299.6	1.18	2.48
13	Summer	1307	17	8	6	5	19	24.6	346.2	1.23	2.54
13	Summer	1308	20	8	6	6	20	25.25	418.35	1.30	2.62
13	Summer	1309	22	8	6	6	20	20.15	459.55	1.34	2.66
13	Summer	1310	24	8	6	6	20	19.95	502.75	1.38	2.70

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
13	Summer	1311	27	8	6	6	20	21.2	562.5	1.43	2.75
13	Summer	1312	31	8	6	6	20	23	648.3	1.49	2.81
13	Summer	1313	34	8	6	6	20	22	715.95	1.53	2.85
13	Summer	1314	45	8	6	6	20	23.45	957.2	1.65	2.98
13	Summer	1315	52	8	6	6	20	24.5	1126.3	1.72	3.05
13	Summer	1316	56	8	7	6	21	23.5	1219.5	1.75	3.09
13	Summer	1317	59	8	7	6	21	24.75	1290.85	1.77	3.11
13	Summer	1318	63	8	7	6	21	19.75	1378.1	1.80	3.14
13	Summer	1319	70	9	8	7	24	25	1540.9	1.85	3.19
13	Summer	1320	84	9	8	7	24	23.85	1868.2	1.92	3.27
13	Summer	1321	92	9	8	7	24	24.75	2059.8	1.96	3.31
13	Summer	1322	94	10	9	7	26	24.4	2108.15	1.97	3.32
13	Summer	1323	112	11	9	8	28	23.9	2518.3	2.05	3.40
14	Summer	1401	1	-	-	-	-	18.2	18.2	0.00	1.26
14	Summer	1402	4	-	-	-	-	20.25	77.85	0.60	1.89
14	Summer	1403	6	6	4	4	14	22.8	123.95	0.78	2.09
14	Summer	1404	8	8	5	6	19	24.6	170.55	0.90	2.23
14	Summer	1405	11	8	7	6	21	25.25	242.7	1.04	2.39
14	Summer	1406	13	8	7	6	21	20.15	283.9	1.11	2.45
14	Summer	1407	15	8	7	6	21	19.95	327.1	1.18	2.51
14	Summer	1408	18	8	7	6	21	21.2	386.85	1.26	2.59
14	Summer	1409	22	8	7	6	21	23	472.65	1.34	2.67
14	Summer	1410	25	8	7	6	21	22	540.3	1.40	2.73
14	Summer	1411	27	8	7	6	21	18.75	579.9	1.43	2.76
14	Summer	1412	29	8	7	6	21	20.05	619.95	1.46	2.79
14	Summer	1413	32	8	7	6	21	23.45	687.15	1.51	2.84
14	Summer	1414	36	8	7	6	21	23.45	781.55	1.56	2.89
14	Summer	1415	40	8	7	6	21	24.7	877.2	1.60	2.94
14	Summer	1416	43	8	7	6	21	24.5	950.65	1.63	2.98
14	Summer	1417	47	8	7	6	21	23.5	1043.85	1.67	3.02

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
14	Summer	1418	50	8	7	8	23	24.75	1115.2	1.70	3.05
14	Summer	1419	54	8	7	8	23	19.75	1202.45	1.73	3.08
14	Summer	1420	57	8	7	8	23	22.45	1268.5	1.76	3.10
14	Summer	1421	61	10	7	8	25	25	1365.25	1.79	3.14
14	Summer	1422	75	10	8	8	26	23.85	1692.55	1.88	3.23
14	Summer	1423	77	10	8	8	26	26.25	1745.2	1.89	3.24
14	Summer	1424	83	10	9	8	27	24.75	1884.15	1.92	3.28
14	Summer	1425	85	10	9	8	27	24.4	1932.5	1.93	3.29
14	Summer	1426	89	11	9	8	28	22.4	2029.5	1.95	3.31
14	Summer	1427	91	11	10	8	29	20.1	2072.7	1.96	3.32
14	Summer	1428	96	11	10	8	29	22.85	2186.45	1.98	3.34
14	Summer	1429	99	11	10	8	29	19.4	2248	2.00	3.35
14	Summer	1430	103	11	10	8	29	23.9	2342.65	2.01	3.37
15	Summer	1501	3	4	4	3	11	22.8	66.35	0.48	1.82
15	Summer	1502	5	6	6	5	17	24.6	112.95	0.70	2.05
15	Summer	1503	8	7	7	6	20	25.25	185.1	0.90	2.27
15	Summer	1504	10	7	7	6	20	20.15	226.3	1.00	2.35
15	Summer	1505	12	7	7	6	20	19.95	269.5	1.08	2.43
15	Summer	1506	15	7	7	6	20	21.2	329.25	1.18	2.52
15	Summer	1507	19	7	7	6	20	23	415.05	1.28	2.62
15	Summer	1508	22	7	7	6	20	22	482.7	1.34	2.68
15	Summer	1509	24	7	7	6	20	18.75	522.3	1.38	2.72
15	Summer	1510	26	7	7	6	20	20.05	562.35	1.41	2.75
15	Summer	1511	29	7	7	6	20	23.45	629.55	1.46	2.80
15	Summer	1512	33	7	7	6	20	23.45	723.95	1.52	2.86
15	Summer	1513	37	7	7	6	20	24.7	819.6	1.57	2.91
15	Summer	1514	40	8	7	6	21	24.5	893.05	1.60	2.95
15	Summer	1515	44	8	7	6	21	23.5	986.25	1.64	2.99
15	Summer	1516	47	8	7	8	23	24.75	1057.6	1.67	3.02
15	Summer	1517	51	8	7	8	23	19.75	1144.85	1.71	3.06

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
15	Summer	1518	54	8	7	8	23	22.45	1210.9	1.73	3.08
15	Summer	1519	58	10	7	8	25	25	1307.65	1.76	3.12
15	Summer	1520	72	10	8	8	26	23.85	1634.95	1.86	3.21
15	Summer	1521	74	10	8	8	26	26.25	1687.6	1.87	3.23
15	Summer	1522	80	10	9	8	27	24.75	1826.55	1.90	3.26
15	Summer	1523	82	11	10	8	29	24.4	1874.9	1.91	3.27
15	Summer	1524	86	11	10	8	29	22.4	1971.9	1.93	3.29
15	Summer	1525	88	11	10	8	29	20.1	2015.1	1.94	3.30
15	Summer	1526	93	11	10	8	29	22.85	2128.85	1.97	3.33
15	Summer	1527	96	11	10	8	29	19.4	2190.4	1.98	3.34
15	Summer	1528	100	11	10	8	29	23.9	2285.05	2.00	3.36
15	Summer	1529	102	11	10	8	29	19.1	2325.35	2.01	3.37
16	Summer	1601	3	2	2	2	6	22.8	66.35	0.48	1.82
16	Summer	1602	5	6	5	4	15	24.6	112.95	0.70	2.05
16	Summer	1603	8	7	7	6	20	25.25	185.1	0.90	2.27
16	Summer	1604	10	7	7	6	20	20.15	226.3	1.00	2.35
16	Summer	1605	12	7	7	6	20	19.95	269.5	1.08	2.43
16	Summer	1606	15	7	8	6	21	21.2	329.25	1.18	2.52
16	Summer	1607	19	7	8	6	21	23	415.05	1.28	2.62
16	Summer	1608	22	7	8	6	21	22	482.7	1.34	2.68
16	Summer	1609	24	7	8	6	21	18.75	522.3	1.38	2.72
16	Summer	1610	26	7	8	6	21	20.05	562.35	1.41	2.75
16	Summer	1611	29	7	8	6	21	23.45	629.55	1.46	2.80
16	Summer	1612	33	10	9	9	28	23.45	723.95	1.52	2.86
16	Summer	1613	37	10	9	9	28	24.7	819.6	1.57	2.91
16	Summer	1614	40	10	9	9	28	24.5	893.05	1.60	2.95
16	Summer	1615	44	10	9	9	28	23.5	986.25	1.64	2.99
16	Summer	1616	47	10	9	9	28	24.75	1057.6	1.67	3.02
16	Summer	1617	51	10	9	9	28	19.75	1144.85	1.71	3.06
16	Summer	1618	54	10	9	9	28	22.45	1210.9	1.73	3.08

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
16	Summer	1619	58	10	9	9	28	25	1307.65	1.76	3.12
16	Summer	1620	72	10	10	9	29	23.85	1634.95	1.86	3.21
16	Summer	1621	74	10	10	9	29	26.25	1687.6	1.87	3.23
16	Summer	1622	80	11	10	9	30	24.75	1826.55	1.90	3.26
16	Summer	1623	82	11	10	9	30	24.4	1874.9	1.91	3.27
16	Summer	1624	86	11	10	9	30	22.4	1971.9	1.93	3.29
16	Summer	1625	88	11	10	9	30	20.1	2015.1	1.94	3.30
16	Summer	1626	93	11	11	9	31	22.85	2128.85	1.97	3.33
16	Summer	1627	96	11	11	9	31	19.4	2190.4	1.98	3.34
16	Summer	1628	100	11	11	9	31	23.9	2285.05	2.00	3.36
16	Summer	1629	102	12	11	9	32	19.1	2325.35	2.01	3.37
17	Summer	1701	1	1	1	1	3	23	23	0.00	1.36
17	Summer	1702	4	5	3	3	11	22	90.65	0.60	1.96
17	Summer	1703	6	-	-	-	-	18.75	130.25	0.78	2.11
17	Summer	1704	8	8	7	8	23	20.05	170.3	0.90	2.23
17	Summer	1705	11	8	7	8	23	23.45	237.5	1.04	2.38
17	Summer	1706	15	8	7	8	23	23.45	331.9	1.18	2.52
17	Summer	1707	19	8	7	8	23	24.7	427.55	1.28	2.63
17	Summer	1708	22	8	7	8	23	24.5	501	1.34	2.70
17	Summer	1709	26	8	7	8	23	23.5	594.2	1.41	2.77
17	Summer	1710	29	8	7	8	23	24.75	665.55	1.46	2.82
17	Summer	1711	33	8	7	8	23	19.75	752.8	1.52	2.88
17	Summer	1712	37	8	7	8	23	22.45	818.85	1.57	2.91
17	Summer	1713	41	10	8	8	26	25	915.6	1.61	2.96
17	Summer	1714	55	10	8	8	26	23.85	1242.9	1.74	3.09
17	Summer	1715	57	10	8	8	26	26.25	1295.55	1.76	3.11
17	Summer	1716	63	10	9	8	27	24.75	1434.5	1.80	3.16
17	Summer	1717	65	10	9	8	27	24.4	1482.85	1.81	3.17
17	Summer	1718	69	10	9	8	27	22.4	1579.85	1.84	3.20
17	Summer	1719	71	11	10	8	29	20.1	1623.05	1.85	3.21

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
17	Summer	1720	76	11	10	8	29	22.85	1736.8	1.88	3.24
17	Summer	1721	79	11	10	8	29	19.4	1798.35	1.90	3.25
17	Summer	1722	83	11	10	8	29	23.9	1893	1.92	3.28
17	Summer	1723	85	11	10	8	29	19.1	1933.3	1.93	3.29
17	Summer	1724	92	11	10	8	29	18.95	2083.3	1.96	3.32
18	Summer	1801	1	1	1	1	3	23	23	0.00	1.36
18	Summer	1802	4	4	5	3	12	22	90.65	0.60	1.96
18	Summer	1803	6	6	6	4	16	18.75	130.25	0.78	2.11
18	Summer	1804	8	7	7	6	20	20.05	170.3	0.90	2.23
18	Summer	1805	11	7	7	6	20	23.45	237.5	1.04	2.38
18	Summer	1806	15	7	7	6	20	23.45	331.9	1.18	2.52
18	Summer	1807	19	7	7	6	20	24.7	427.55	1.28	2.63
18	Summer	1808	22	7	7	6	20	24.5	501	1.34	2.70
18	Summer	1809	26	8	7	6	21	23.5	594.2	1.41	2.77
18	Summer	1810	29	8	7	6	21	24.75	665.55	1.46	2.82
18	Summer	1811	33	8	7	6	21	19.75	752.8	1.52	2.88
18	Summer	1812	37	8	7	6	21	22.45	818.85	1.57	2.91
18	Summer	1813	41	9	7	6	22	25	915.6	1.61	2.96
18	Summer	1814	55	9	7	6	22	23.85	1242.9	1.74	3.09
18	Summer	1815	57	9	7	6	22	26.25	1295.55	1.76	3.11
18	Summer	1816	63	9	7	8	24	24.75	1434.5	1.80	3.16
18	Summer	1817	65	9	8	8	25	24.4	1482.85	1.81	3.17
18	Summer	1818	69	9	8	8	25	22.4	1579.85	1.84	3.20
18	Summer	1819	71	10	9	8	27	20.1	1623.05	1.85	3.21
18	Summer	1820	76	10	9	8	27	22.85	1736.8	1.88	3.24
18	Summer	1821	79	10	9	8	27	19.4	1798.35	1.90	3.25
18	Summer	1822	83	10	9	8	27	23.9	1893	1.92	3.28
18	Summer	1823	85	11	9	8	28	19.1	1933.3	1.93	3.29
18	Summer	1824	92	11	9	8	28	18.95	2083.3	1.96	3.32
19	Summer	1901	1	1	1	1	3	22	22	0.00	1.34

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
19	Summer	1902	3	3	5	3	11	18.75	61.6	0.48	1.79
19	Summer	1903	5	8	6	5	19	20.05	101.65	0.70	2.01
19	Summer	1904	8	8	6	5	19	23.45	168.85	0.90	2.23
19	Summer	1905	12	8	6	6	20	23.45	263.25	1.08	2.42
19	Summer	1906	16	8	6	6	20	24.7	358.9	1.20	2.55
19	Summer	1907	19	8	6	6	20	24.5	432.35	1.28	2.64
19	Summer	1908	23	8	7	6	21	23.5	525.55	1.36	2.72
19	Summer	1909	26	8	7	6	21	24.75	596.9	1.41	2.78
19	Summer	1910	30	8	7	6	21	19.75	684.15	1.48	2.84
19	Summer	1911	33	8	7	6	22	22.45	750.2	1.52	2.88
19	Summer	1912	37	9	7	6	22	25	846.95	1.57	2.93
19	Summer	1913	51	9	7	6	22	23.85	1174.25	1.71	3.07
19	Summer	1914	53	9	7	6	22	26.25	1226.9	1.72	3.09
19	Summer	1915	59	9	7	8	24	24.75	1365.85	1.77	3.14
19	Summer	1916	61	10	7	8	25	24.4	1414.2	1.79	3.15
19	Summer	1917	65	10	7	8	25	22.4	1511.2	1.81	3.18
19	Summer	1918	67	10	8	8	26	20.1	1554.4	1.83	3.19
19	Summer	1919	72	10	8	8	26	22.85	1668.15	1.86	3.22
19	Summer	1920	75	10	8	8	26	19.4	1729.7	1.88	3.24
19	Summer	1921	79	10	8	8	26	23.9	1824.35	1.90	3.26
19	Summer	1922	81	11	8	8	27	19.1	1864.65	1.91	3.27
19	Summer	1923	88	11	9	8	28	18.95	2014.65	1.94	3.30
20	Summer	2001	4	7	5	4	16	23.45	117.85	0.60	2.07
20	Summer	2002	8	7	7	6	20	24.7	213.5	0.90	2.33
20	Summer	2003	11	7	9	6	22	24.5	286.95	1.04	2.46
20	Summer	2004	15	8	9	6	23	23.5	380.15	1.18	2.58
20	Summer	2005	18	8	9	6	23	24.75	451.5	1.26	2.65
20	Summer	2006	22	8	9	6	23	19.75	538.75	1.34	2.73
20	Summer	2007	25	8	9	6	23	22.45	604.8	1.40	2.78
20	Summer	2008	29	10	9	6	23	25	701.55	1.46	2.85

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
20	Summer	2009	43	10	9	7	26	23.85	1028.85	1.63	3.01
20	Summer	2010	45	10	9	7	26	26.25	1081.5	1.65	3.03
20	Summer	2011	51	11	10	8	29	24.75	1220.45	1.71	3.09
20	Summer	2012	53	11	10	8	29	24.4	1268.8	1.72	3.10
20	Summer	2013	57	11	10	8	29	22.4	1365.8	1.76	3.14
20	Summer	2014	59	11	10	8	29	20.1	1409	1.77	3.15
20	Summer	2015	67	11	10	8	29	22.85	1522.75	1.83	3.18
20	Summer	2016	70	11	10	8	29	19.4	1584.3	1.85	3.20
20	Summer	2017	74	11	11	8	30	23.9	1678.95	1.87	3.23
20	Summer	2018	76	11	11	8	30	19.1	1719.25	1.88	3.24
20	Summer	2019	83	12	11	9	31	18.95	1869.25	1.92	3.27
20	Summer	2020	90	12	11	9	32	23.8	2029.1	1.95	3.31
21	Summer	2101	1	1	1	1	3	22.7	22.7	0.00	1.36
21	Summer	2102	4	-	-	-	-	18.95	87.1	0.60	1.94
21	Summer	2103	6	8	7	4	19	21.4	129.85	0.78	2.11
21	Summer	2104	9	8	7	5	20	24.1	199.05	0.95	2.30
21	Summer	2105	11	8	7	6	21	23.8	246.95	1.04	2.39
21	Summer	2106	16	8	7	8	23	19	357.75	1.20	2.55
21	Summer	2107	18	8	7	8	23	23.55	403.8	1.26	2.61
21	Summer	2108	20	9	7	8	24	23.65	452.9	1.30	2.66
21	Summer	2109	25	9	7	8	24	19.2	559.05	1.40	2.75
21	Summer	2110	32	11	7	8	26	22.15	707.95	1.51	2.85
21	Summer	2111	53	11	9	8	28	20.1	1138.3	1.72	3.06
22	Summer	2201	1	1	1	1	3	22.7	22.7	0.00	1.36
22	Summer	2202	4	-	-	-	-	18.95	87.1	0.60	1.94
22	Summer	2203	6	10	9	5	24	21.4	129.85	0.78	2.11
22	Summer	2204	9	10	9	5	24	24.1	199.05	0.95	2.30
22	Summer	2205	11	11	9	6	26	23.8	246.95	1.04	2.39
22	Summer	2206	16	11	9	7	27	19	357.75	1.20	2.55
22	Summer	2207	18	11	11	7	29	23.55	403.8	1.26	2.61

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
22	Summer	2208	20	11	11	7	29	23.65	452.9	1.30	2.66
22	Summer	2209	25	11	11	8	30	19.2	559.05	1.40	2.75
22	Summer	2210	32	12	11	8	31	22.15	707.95	1.51	2.85
22	Summer	2211	53	13	11	9	33	20.1	1138.3	1.72	3.06
23	Summer	2301	3	-	-	-	-	18.95	64.4	0.48	1.81
23	Summer	2302	5	5	5	3	13	21.4	107.15	0.70	2.03
23	Summer	2303	8	8	7	5	20	24.1	176.35	0.90	2.25
23	Summer	2304	10	8	7	6	21	23.8	224.25	1.00	2.35
23	Summer	2305	15	8	7	6	21	19	335.05	1.18	2.53
23	Summer	2306	17	8	9	6	23	23.55	381.1	1.23	2.58
23	Summer	2307	19	9	9	7	25	23.65	430.2	1.28	2.63
23	Summer	2308	24	10	9	8	27	19.2	536.35	1.38	2.73
23	Summer	2309	31	10	9	8	27	22.15	685.25	1.49	2.84
23	Summer	2310	52	11	10	9	30	20.1	1115.6	1.72	3.05
24	Summer	2401	3	-	-	-	-	18.95	64.4	0.48	1.81
24	Summer	2402	5	5	4	3	17	21.4	107.15	0.70	2.03
24	Summer	2403	8	8	7	5	20	24.1	176.35	0.90	2.25
24	Summer	2404	10	10	7	6	23	23.8	224.25	1.00	2.35
24	Summer	2405	15	10	7	6	23	19	335.05	1.18	2.53
24	Summer	2406	17	10	9	8	27	23.55	381.1	1.23	2.58
24	Summer	2407	19	10	9	8	27	23.65	430.2	1.28	2.63
24	Summer	2408	24	10	9	8	27	19.2	536.35	1.38	2.73
24	Summer	2409	31	10	9	8	27	22.15	685.25	1.49	2.84
24	Summer	2410	52	12	10	8	30	20.1	1115.6	1.72	3.05
25	Summer	2501	3	5	4	4	13	21.4	61.7	0.48	1.79
25	Summer	2502	6	7	6	5	18	24.1	130.9	0.78	2.12
25	Summer	2503	8	8	7	5	20	23.8	178.8	0.90	2.25
25	Summer	2504	13	8	7	6	21	19	289.6	1.11	2.46
25	Summer	2505	15	8	7	6	21	23.55	335.65	1.18	2.53
25	Summer	2506	17	9	7	8	24	23.65	384.75	1.23	2.59

Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
25	Summer	2507	22	10	8	8	26	19.2	490.9	1.34	2.69
25	Summer	2508	29	10	9	8	27	22.15	639.8	1.46	2.81
25	Summer	2509	50	11	10	8	29	20.1	1070.15	1.70	3.03
26	Summer	2601	3	4	4	2	10	21.4	61.7	0.48	1.79
26	Summer	2602	6	8	7	5	22	24.1	130.9	0.78	2.12
26	Summer	2603	8	8	7	6	23	23.8	178.8	0.90	2.25
26	Summer	2604	13	10	7	8	25	19	289.6	1.11	2.46
26	Summer	2605	15	10	7	8	25	23.55	335.65	1.18	2.53
26	Summer	2606	17	11	8	8	27	23.65	384.75	1.23	2.59
26	Summer	2607	22	12	9	8	29	19.2	490.9	1.34	2.69
26	Summer	2608	29	12	10	8	30	22.15	639.8	1.46	2.81
26	Summer	2609	50	13	11	9	33	20.1	1070.15	1.70	3.03
27	Summer	2701	2	1	3	1	5	19	39.5	0.30	1.60
27	Summer	2702	3	3	3	3	9	22.5	62	0.48	1.79
27	Summer	2703	4	3	4	3	10	23.55	85.55	0.60	1.93
27	Summer	2704	6	5	7	6	18	23.65	134.65	0.78	2.13
27	Summer	2705	11	8	7	6	21	19.2	240.8	1.04	2.38
27	Summer	2706	18	10	7	6	23	22.15	389.7	1.26	2.59
27	Summer	2707	39	11	9	8	28	20.1	820.05	1.59	2.91
28	Summer	2801	2	1	3	1	5	19	39.5	0.30	1.60
28	Summer	2802	3	3	3	2	8	22.5	62	0.48	1.79
28	Summer	2803	4	3	3	2	8	23.55	85.55	0.60	1.93
28	Summer	2804	6	5	5	4	14	23.65	134.65	0.78	2.13
28	Summer	2805	11	8	7	6	21	19.2	240.8	1.04	2.38
28	Summer	2806	18	10	8	6	24	22.15	389.7	1.26	2.59
28	Summer	2807	39	11	9	8	28	20.1	820.05	1.59	2.91
29	Summer	2901	2	1	1	1	3	19	39.5	0.30	1.60
29	Summer	2902	3	3	3	2	8	22.5	62	0.48	1.79
29	Summer	2903	4	3	4	3	10	23.55	85.55	0.60	1.93
29	Summer	2904	6	5	5	5	15	23.65	134.65	0.78	2.13

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Pig	Season	Observation	pmi_val	han_sco	tru_sco	lim_sco	tbs_val	tem_ave	add_val	log_pmi	log_add
29	Summer	2905	11	10	7	6	23	19.2	240.8	1.04	2.38
29	Summer	2906	18	12	7	6	25	22.15	389.7	1.26	2.59
29	Summer	2907	39	12	8	6	26	20.1	820.05	1.59	2.91
30	Summer	3001	2	1	1	1	3	19	39.5	0.30	1.60
30	Summer	3002	3	3	3	2	8	22.5	62	0.48	1.79
30	Summer	3003	4	3	4	3	10	23.55	85.55	0.60	1.93
30	Summer	3004	6	5	5	5	15	23.65	134.65	0.78	2.13
30	Summer	3005	11	10	7	6	23	19.2	240.8	1.04	2.38
30	Summer	3006	18	12	7	6	25	22.15	389.7	1.26	2.59
30	Summer	3007	39	12	8	6	26	20.1	820.05	1.59	2.91

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APPENDIX D: Data for interobserver error analysis

Appendix D.1: Results of the repeatability of head and neck score (Orig = Original score and Inter = Interobserver results)

Pig	Observation	han_sco (Orig)	han_sco (Inter)
1	101	1	1
1	102	1	1
1	103	3	1
1	104	3	3
1	105	4	3
1	106	4	4
1	107	4	4
1	108	6	6
1	109	6	6
1	110	6	7
1	111	7	7
1	112	7	7
1	113	7	7
1	114	7	7
1	115	7	7
1	116	7	7
1	117	7	7
1	118	7	7
1	119	7	7
1	120	7	7
1	121	7	7
1	122	7	7
1	123	7	7
1	124	7	7
1	125	7	7
1	126	7	7
1	127	7	7
1	128	7	7
1	129	7	7
1	130	7	7
1	131	7	7
1	132	7	7
1	133	7	7
1	134	7	7
1	135	8	8
1	136	8	8
1	137	8	8
1	138	10	10
1	139	12	12
2	201	1	1
2	202	1	1
2	203	3	4
2	204	4	4
2	205	4	5
2	206	7	6
2	207	7	6
2	208	7	7
2	209	7	7
2	210	7	7

Pig	Observation	han_sco (Orig)	han_sco (Inter)
2	211	7	7
2	212	7	7
2	213	7	7
2	214	7	7
2	215	7	7
2	216	7	7
2	217	7	7
2	218	7	7
2	219	7	7
2	220	7	7
2	221	7	7
2	222	7	7
2	223	7	7
2	224	7	7
2	225	7	7
2	226	7	7
2	227	7	7
2	228	7	7
2	229	7	7
2	230	7	7
2	231	7	7
2	232	7	7
2	233	7	7
2	234	11	11
2	235	13	13
3	301	1	1
3	302	1	3
3	303	3	4
3	304	4	4
3	305	4	4
3	306	5	5
3	307	6	6
3	308	6	6
3	309	7	6
3	310	7	6
3	311	7	7
3	312	7	7
3	313	7	7
3	314	7	7
3	315	7	7
3	316	7	7
3	317	7	8
3	318	7	8
3	319	7	8
3	320	7	8
3	321	7	8
3	322	7	8
3	323	7	8
3	324	7	8
3	325	7	8
3	326	7	8
3	327	7	8
3	328	8	8
3	329	8	8
3	330	8	8
3	331	8	8
3	332	8	8

Pig	Observation	han_sco (Orig)	han_sco (Inter)
3	333	8	8
3	334	9	9
4	401	1	1
4	402	1	1
4	403	2	2
4	404	4	7
4	405	7	7
4	406	7	7
4	407	8	8
4	408	8	8
4	409	8	8
4	410	8	8
4	411	8	8
4	412	8	8
4	413	8	8
4	414	8	8
4	415	8	8
4	416	8	8
4	417	8	8
4	418	8	8
4	419	8	8
4	420	8	8
4	421	8	8
4	422	8	8
4	423	8	8
4	424	8	8
4	425	8	8
4	426	8	8
4	427	8	8
4	428	8	8
4	429	8	8
4	430	8	8
4	431	8	8
4	432	8	8
4	433	8	8
4	434	11	11
4	435	11	11
5	501	1	1
5	502	1	1
5	503	2	2
5	504	5	4
5	505	5	4
5	506	6	4
5	507	7	5
5	508	7	6
5	509	7	7
5	510	7	7
5	511	7	7
5	512	7	7
5	513	7	7
5	514	7	7
5	515	7	7
5	516	7	7
5	517	7	7
5	518	7	7
5	519	7	7
5	520	7	7

Pig	Observation	han_sco (Orig)	han_sco (Inter)
5	521	7	7
5	522	7	7
5	523	7	7
5	524	7	7
5	525	7	7
5	526	7	7
5	527	7	7
5	528	7	7
5	529	7	7
5	530	7	7
5	531	8	8
5	532	9	9
6	601	1	1
6	602	1	2
6	603	3	3
6	604	4	5
6	605	5	5
6	606	7	6
6	607	7	7
6	608	7	7
6	609	7	7
6	610	7	7
6	611	7	7
6	612	7	7
6	613	7	7
6	614	7	7
6	615	7	7
6	616	7	7
6	617	7	7
6	618	7	7
6	619	7	7
6	620	7	7
6	621	7	7
6	622	7	7
6	623	7	7
6	624	7	7
6	625	8	8
6	626	8	8
6	627	8	8
6	628	8	8
6	629	8	8
6	630	11	11
6	631	12	12
7	701	1	1
7	702	1	2
7	703	2	3
7	704	2	3
7	705	4	4
7	706	5	6
7	707	6	6
7	708	6	6
7	709	6	6
7	710	7	6
7	711	7	6
7	712	7	6
7	713	7	6
7	714	7	7

Pig	Observation	han_sco (Orig)	han_sco (Inter)
7	715	7	7
7	716	7	7
7	717	7	7
7	718	7	7
7	719	7	7
7	720	7	7
7	721	7	7
7	722	7	7
7	723	7	7
7	724	7	7
7	725	7	7
7	726	7	7
7	727	9	9
7	728	11	11
7	729	12	12
8	801	1	1
8	802	1	2
8	803	2	2
8	804	5	4
8	805	6	5
8	806	7	5
8	807	7	7
8	808	7	7
8	809	8	8
8	810	8	8
8	811	8	8
8	812	8	8
8	813	8	8
8	814	8	8
8	815	8	8
8	816	8	8
8	817	8	8
8	818	8	8
8	819	8	8
8	820	8	8
8	821	8	8
8	822	8	8
8	823	8	8
8	824	8	8
8	825	8	8
8	826	8	8
8	827	8	8
8	828	9	9
8	829	10	10
9	901	1	1
9	902	5	5
9	903	8	8
9	904	8	8
9	905	8	8
9	906	8	8
9	907	8	8
9	908	8	8
9	909	8	8
9	910	8	8
9	911	8	8
9	912	8	8
9	913	8	8

Pig	Observation	han_sco (Orig)	han_sco (Inter)
9	914	8	8
9	915	8	8
9	916	8	8
9	917	8	8
9	918	10	10
9	919	10	10
9	920	10	10
9	921	10	10
9	922	10	10
9	923	11	11
9	924	13	13
9	925	13	13
9	926	13	13
10	1001	2	2
10	1002	4	4
10	1003	9	9
10	1004	9	9
10	1005	9	9
10	1006	9	9
10	1007	9	9
10	1008	9	9
10	1009	9	9
10	1010	9	9
10	1011	10	10
10	1012	10	10
10	1013	10	10
10	1014	10	10
10	1015	10	10
10	1016	10	10
10	1017	13	13
10	1018	13	13
10	1019	13	13

Appendix D.2: Results of the repeatability of trunk score (Orig = Original score and Inter = Interobserver results)

Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
1	101	1	1
1	102	1	1
1	103	3	4
1	104	4	4
1	105	4	4
1	106	4	4
1	107	4	4
1	108	5	4
1	109	5	5
1	110	5	6
1	111	6	6
1	112	6	6
1	113	6	6
1	114	6	6
1	115	6	6

Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
1	116	6	6
1	117	6	6
1	118	6	6
1	119	6	6
1	120	6	6
1	121	6	6
1	122	6	6
1	123	6	6
1	124	6	6
1	125	6	6
1	126	6	6
1	127	6	6
1	128	6	6
1	129	6	6
1	130	6	6
1	131	6	6
1	132	6	6
1	133	6	6
1	134	6	6
1	135	6	6
1	136	6	6
1	137	7	7
1	138	8	8
1	139	10	10
2	201	3	3
2	202	3	4
2	203	4	4
2	204	4	4
2	205	4	4
2	206	5	5
2	207	6	5
2	208	6	6
2	209	6	6
2	210	6	6
2	211	6	6
2	212	6	6
2	213	6	6
2	214	6	6
2	215	6	6
2	216	6	6
2	217	6	6
2	218	6	6
2	219	6	6
2	220	6	6
2	221	6	6
2	222	6	6
2	223	6	6
2	224	6	6
2	225	6	6
2	226	6	6
2	227	6	6
2	228	6	6
2	229	7	7
2	230	7	7

Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
2	231	7	7
2	232	7	7
2	233	7	7
2	234	10	10
2	235	10	10
3	301	3	3
3	302	4	4
3	303	4	4
3	304	4	4
3	305	5	5
3	306	6	5
3	307	6	6
3	308	6	6
3	309	6	6
3	310	6	6
3	311	6	6
3	312	6	6
3	313	6	6
3	314	6	6
3	315	6	6
3	316	6	6
3	317	6	6
3	318	6	6
3	319	6	6
3	320	6	6
3	321	6	6
3	322	6	6
3	323	6	6
3	324	6	6
3	325	6	6
3	326	6	6
3	327	6	6
3	328	6	6
3	329	6	6
3	330	6	6
3	331	7	7
3	332	7	7
3	333	7	7
3	334	8	8
4	401	1	1
4	402	1	1
4	403	3	2
4	404	5	6
4	405	6	6
4	406	6	6
4	407	6	6
4	408	6	6
4	409	6	6
4	410	6	6
4	411	6	6
4	412	6	6
4	413	6	6
4	414	6	6
4	415	6	6

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Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
4	416	6	6
4	417	6	6
4	418	6	6
4	419	6	6
4	420	6	6
4	421	6	6
4	422	6	6
4	423	6	6
4	424	6	6
4	425	6	6
4	426	6	6
4	427	6	6
4	428	6	6
4	429	6	6
4	430	6	6
4	431	6	6
4	432	6	6
4	433	7	7
4	434	10	10
4	435	10	10
5	501	1	1
5	502	1	1
5	503	4	2
5	504	4	2
5	505	4	2
5	506	4	4
5	507	5	4
5	508	5	4
5	509	5	5
5	510	5	5
5	511	5	5
5	512	5	5
5	513	5	5
5	514	5	5
5	515	5	5
5	516	5	5
5	517	5	5
5	518	5	5
5	519	5	5
5	520	5	5
5	521	5	5
5	522	6	6
5	523	6	6
5	524	6	6
5	525	6	6
5	526	6	6
5	527	6	6
5	528	6	6
5	529	6	6
5	530	6	6
5	531	7	7
5	532	8	8
6	601	1	1
6	602	4	4

Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
6	603	5	5
6	604	6	6
6	605	6	6
6	606	6	6
6	607	6	6
6	608	6	7
6	609	7	7
6	610	7	7
6	611	7	7
6	612	7	7
6	613	7	7
6	614	7	7
6	615	7	7
6	616	7	7
6	617	7	7
6	618	7	7
6	619	7	7
6	620	7	7
6	621	7	7
6	622	7	7
6	623	7	7
6	624	7	7
6	625	7	7
6	626	7	7
6	627	7	7
6	628	7	7
6	629	7	7
6	630	10	10
6	631	10	10
7	701	1	1
7	702	3	3
7	703	4	4
7	704	5	5
7	705	5	5
7	706	6	5
7	707	6	6
7	708	6	6
7	709	6	6
7	710	6	6
7	711	6	6
7	712	6	6
7	713	6	6
7	714	6	6
7	715	6	6
7	716	6	6
7	717	6	6
7	718	6	6
7	719	6	6
7	720	6	6
7	721	6	6
7	722	6	6
7	723	6	6
7	724	6	6
7	725	6	6

Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
7	726	6	6
7	727	6	6
7	728	8	8
7	729	9	9
8	801	1	1
8	802	1	2
8	803	4	4
8	804	5	5
8	805	6	6
8	806	6	6
8	807	7	6
8	808	7	6
8	809	7	7
8	810	7	7
8	811	7	7
8	812	7	7
8	813	7	7
8	814	7	7
8	815	7	7
8	816	7	7
8	817	7	7
8	818	7	7
8	819	7	7
8	820	7	7
8	821	7	7
8	822	7	7
8	823	7	7
8	824	7	7
8	825	7	7
8	826	7	7
8	827	7	7
8	828	8	8
8	829	9	9
9	901	1	2
9	902	4	5
9	903	7	7
9	904	7	7
9	905	7	7
9	906	7	7
9	907	7	7
9	908	7	7
9	909	7	7
9	910	7	7
9	911	7	7
9	912	7	7
9	913	7	7
9	914	7	7
9	915	7	7
9	916	8	8
9	917	8	8
9	918	9	9
9	919	10	10
9	920	10	10
9	921	10	10

Pig	Observation	tru_sco (Orig)	tru_sco (Inter)
9	922	10	10
9	923	11	11
9	924	11	11
9	925	12	12
9	926	12	12
10	1001	3	3
10	1002	4	4
10	1003	7	7
10	1004	7	7
10	1005	7	7
10	1006	7	7
10	1007	7	7
10	1008	7	7
10	1009	7	7
10	1010	7	7
10	1011	7	7
10	1012	7	7
10	1013	7	7
10	1014	7	7
10	1015	7	7
10	1016	10	10
10	1017	10	10
10	1018	12	12
10	1019	12	12

Appendix D.3: Results of the repeatability of limbs score (Orig = Original score and Inter = Interobserver results)

Pig	Observation	lim_sco (Orig)	lim_sco (Inter)
1	101	1	1
1	102	1	1
1	103	1	1
1	104	3	3
1	105	3	3
1	106	3	3
1	107	4	4
1	108	5	5
1	109	5	5
1	110	5	5
1	111	5	5
1	112	5	5
1	113	5	5
1	114	5	5
1	115	5	5
1	116	5	5
1	117	5	5
1	118	5	5
1	119	6	6
1	120	6	6
1	121	6	6
1	122	6	6
1	123	6	6
1	124	6	6

Pig	Observation	lim_sco (Orig)	lim_sco (Inter)
1	125	6	6
1	126	6	6
1	127	6	6
1	128	6	6
1	129	6	6
1	130	6	6
1	131	6	6
1	132	6	6
1	133	6	6
1	134	6	6
1	135	6	6
1	136	6	6
1	137	8	8
1	138	8	8
1	139	9	9
2	201	1	1
2	202	1	1
2	203	1	2
2	204	3	3
2	205	4	4
2	206	4	4
2	207	5	4
2	208	5	4
2	209	5	4
2	210	5	5
2	211	5	5
2	212	5	5
2	213	5	5
2	214	5	5
2	215	5	5
2	216	5	5
2	217	5	5
2	218	5	5
2	219	5	5
2	220	5	5
2	221	5	5
2	222	5	5
2	223	5	5
2	224	5	5
2	225	5	5
2	226	5	5
2	227	5	5
2	228	5	5
2	229	5	5
2	230	5	5
2	231	6	6
2	232	6	6
2	233	8	8
2	234	8	8
2	235	9	9
3	301	1	1
3	302	3	3
3	303	3	3
3	304	4	4
3	305	5	5
3	306	5	5
3	307	5	5

Pig	Observation	lim_sco (Orig)	lim_sco (Inter)
3	308	5	5
3	309	5	5
3	310	5	5
3	311	5	5
3	312	5	5
3	313	5	5
3	314	5	5
3	315	5	5
3	316	5	5
3	317	5	5
3	318	5	5
3	319	5	5
3	320	5	5
3	321	5	5
3	322	5	5
3	323	5	5
3	324	5	5
3	325	5	5
3	326	5	5
3	327	5	5
3	328	5	5
3	329	5	5
3	330	6	6
3	331	6	6
3	332	6	6
3	333	8	8
3	334	8	8
4	401	1	1
4	402	1	1
4	403	1	1
4	404	4	5
4	405	5	5
4	406	5	5
4	407	5	5
4	408	5	5
4	409	5	5
4	410	5	6
4	411	5	6
4	412	5	6
4	413	6	6
4	414	6	6
4	415	6	6
4	416	6	6
4	417	6	6
4	418	6	6
4	419	6	6
4	420	6	6
4	421	6	6
4	422	6	6
4	423	6	6
4	424	6	6
4	425	6	6
4	426	6	6
4	427	6	6
4	428	6	6
4	429	6	6
4	430	6	6

Pig	Observation	lim_sco (Orig)	lim_sco (Inter)
4	431	6	6
4	432	6	6
4	433	8	8
4	434	8	8
4	435	9	9
5	501	1	1
5	502	1	1
5	503	2	2
5	504	3	3
5	505	3	3
5	506	5	4
5	507	5	4
5	508	5	4
5	509	5	4
5	510	5	4
5	511	5	4
5	512	5	5
5	513	5	5
5	514	5	5
5	515	5	5
5	516	5	5
5	517	5	5
5	518	5	5
5	519	5	5
5	520	5	5
5	521	5	5
5	522	5	5
5	523	5	5
5	524	5	5
5	525	5	5
5	526	5	5
5	527	5	5
5	528	6	6
5	529	6	6
5	530	6	6
5	531	8	8
5	532	8	8
6	601	1	1
6	602	1	3
6	603	4	4
6	604	5	5
6	605	5	5
6	606	5	5
6	607	5	5
6	608	5	5
6	609	5	5
6	610	5	5
6	611	5	5
6	612	5	5
6	613	5	5
6	614	5	5
6	615	5	5
6	616	5	5
6	617	5	5
6	618	5	5
6	619	6	6
6	620	6	6

Pig	Observation	lim_sco (Orig)	lim_sco (Inter)
6	621	6	6
6	622	6	6
6	623	6	6
6	624	6	6
6	625	6	6
6	626	6	6
6	627	6	6
6	628	6	6
6	629	8	8
6	630	8	8
6	631	9	9
7	701	1	1
7	702	1	1
7	703	3	3
7	704	3	3
7	705	5	5
7	706	5	5
7	707	5	5
7	708	5	5
7	709	5	5
7	710	5	5
7	711	5	5
7	712	5	5
7	713	5	5
7	714	5	5
7	715	5	5
7	716	5	5
7	717	5	5
7	718	5	5
7	719	5	5
7	720	5	5
7	721	5	5
7	722	5	5
7	723	5	5
7	724	5	5
7	725	6	6
7	726	6	6
7	727	8	8
7	728	9	9
7	729	9	9
8	801	1	1
8	802	1	1
8	803	2	2
8	804	5	6
8	805	5	6
8	806	5	6
8	807	6	6
8	808	6	6
8	809	6	6
8	810	6	6
8	811	6	6
8	812	6	6
8	813	6	6
8	814	6	6
8	815	6	6
8	816	6	6
8	817	6	6

Pig	Observation	lim_sco (Orig)	lim_sco (Inter)
8	818	6	6
8	819	6	6
8	820	6	6
8	821	6	6
8	822	6	6
8	823	6	6
8	824	6	6
8	825	6	6
8	826	8	8
8	827	8	8
8	828	8	8
8	829	9	9
9	901	1	1
9	902	3	3
9	903	6	6
9	904	6	6
9	905	6	6
9	906	6	6
9	907	6	6
9	908	6	6
9	909	6	6
9	910	6	6
9	911	6	6
9	912	6	6
9	913	6	6
9	914	6	6
9	915	6	6
9	916	8	8
9	917	8	8
9	918	8	8
9	919	10	10
9	920	10	10
9	921	10	10
9	922	10	10
9	923	10	10
9	924	10	10
9	925	10	10
9	926	10	10
10	1001	1	1
10	1002	3	3
10	1003	6	6
10	1004	6	6
10	1005	6	6
10	1006	6	6
10	1007	6	6
10	1008	6	6
10	1009	6	6
10	1010	6	6
10	1011	6	6
10	1012	6	6
10	1013	8	8
10	1014	8	8
10	1015	8	8
10	1016	9	9
10	1017	10	10
10	1018	10	10
10	1019	10	10

Appendix D.4: Results of the repeatability of Total Body Score (TBS) (Orig = Original score and Inter = Interobserver results)

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
1	101	3	3
1	102	3	3
1	103	7	6
1	104	10	10
1	105	11	10
1	106	11	11
1	107	12	12
1	108	16	15
1	109	16	16
1	110	16	18
1	111	18	18
1	112	18	18
1	113	18	18
1	114	18	18
1	115	18	18
1	116	18	18
1	117	18	18
1	118	18	18
1	119	19	19
1	120	19	19
1	121	19	19
1	122	19	19
1	123	19	19
1	124	19	19
1	125	19	19
1	126	19	19
1	127	19	19
1	128	19	19
1	129	19	19
1	130	19	19
1	131	19	19
1	132	19	19
1	133	19	19
1	134	19	19
1	135	20	20
1	136	20	20
1	137	23	23
1	138	26	26
1	139	31	31
2	201	5	5
2	202	5	6
2	203	8	10
2	204	11	11
2	205	12	13
2	206	16	15
2	207	18	15
2	208	18	17

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
2	209	18	17
2	210	18	18
2	211	18	18
2	212	18	18
2	213	18	18
2	214	18	18
2	215	18	18
2	216	18	18
2	217	18	18
2	218	18	18
2	219	18	18
2	220	18	18
2	221	18	18
2	222	18	18
2	223	18	18
2	224	18	18
2	225	18	18
2	226	18	18
2	227	18	18
2	228	18	18
2	229	19	19
2	230	19	19
2	231	20	20
2	232	20	20
2	233	22	22
2	234	29	29
2	235	32	32
3	301	5	5
3	302	8	9
3	303	10	11
3	304	12	12
3	305	14	14
3	306	16	15
3	307	17	17
3	308	17	17
3	309	18	17
3	310	18	17
3	311	18	18
3	312	18	18
3	313	18	18
3	314	18	18
3	315	18	18
3	316	18	18
3	317	18	19
3	318	18	19
3	319	18	19
3	320	18	19
3	321	18	19
3	322	18	19
3	323	18	19
3	324	18	19

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
3	325	18	19
3	326	18	19
3	327	18	19
3	328	19	19
3	329	19	19
3	330	20	20
3	331	21	21
3	332	21	21
3	333	23	23
3	334	25	25
4	401	3	3
4	402	3	3
4	403	6	5
4	404	13	18
4	405	18	18
4	406	18	18
4	407	19	19
4	408	19	19
4	409	19	19
4	410	19	20
4	411	19	20
4	412	19	20
4	413	20	20
4	414	20	20
4	415	20	20
4	416	20	20
4	417	20	20
4	418	20	20
4	419	20	20
4	420	20	20
4	421	20	20
4	422	20	20
4	423	20	20
4	424	20	20
4	425	20	20
4	426	20	20
4	427	20	20
4	428	20	20
4	429	20	20
4	430	20	20
4	431	20	20
4	432	20	20
4	433	23	23
4	434	29	29
4	435	30	30
5	501	3	3
5	502	3	3
5	503	8	6
5	504	12	9
5	505	12	9
5	506	15	12

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
5	507	17	13
5	508	17	14
5	509	17	16
5	510	17	16
5	511	17	16
5	512	17	17
5	513	17	17
5	514	17	17
5	515	17	17
5	516	17	17
5	517	17	17
5	518	17	17
5	519	17	17
5	520	17	17
5	521	17	17
5	522	18	18
5	523	18	18
5	524	18	18
5	525	18	18
5	526	18	18
5	527	18	18
5	528	19	19
5	529	19	19
5	530	19	19
5	531	23	23
5	532	25	25
6	601	3	3
6	602	6	9
6	603	12	12
6	604	15	16
6	605	16	16
6	606	18	17
6	607	18	18
6	608	18	19
6	609	19	19
6	610	19	19
6	611	19	19
6	612	19	19
6	613	19	19
6	614	19	19
6	615	19	19
6	616	19	19
6	617	19	19
6	618	19	19
6	619	20	20
6	620	20	20
6	621	20	20
6	622	20	20
6	623	20	20
6	624	20	20
6	625	21	21

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
6	626	21	21
6	627	21	21
6	628	21	21
6	629	23	23
6	630	29	29
6	631	31	31
7	701	3	3
7	702	5	6
7	703	9	10
7	704	10	10
7	705	14	14
7	706	16	16
7	707	17	17
7	708	17	17
7	709	17	17
7	710	18	17
7	711	18	17
7	712	18	17
7	713	18	17
7	714	18	18
7	715	18	18
7	716	18	18
7	717	18	18
7	718	18	18
7	719	18	18
7	720	18	18
7	721	18	18
7	722	18	18
7	723	18	18
7	724	18	18
7	725	19	19
7	726	19	19
7	727	23	23
7	728	28	28
7	729	30	30
8	801	3	3
8	802	3	5
8	803	8	8
8	804	15	15
8	805	17	17
8	806	18	17
8	807	20	19
8	808	20	20
8	809	21	21
8	810	21	21
8	811	21	21
8	812	21	21
8	813	21	21
8	814	21	21
8	815	21	21
8	816	21	21

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
8	817	21	21
8	818	21	21
8	819	21	21
8	820	21	21
8	821	21	21
8	822	21	21
8	823	21	21
8	824	21	21
8	825	21	21
8	826	23	23
8	827	23	23
8	828	25	25
8	829	28	28
9	901	3	4
9	902	12	13
9	903	21	21
9	904	21	21
9	905	21	21
9	906	21	21
9	907	21	21
9	908	21	21
9	909	21	21
9	910	21	21
9	911	21	21
9	912	21	21
9	913	21	21
9	914	21	21
9	915	21	21
9	916	24	24
9	917	24	24
9	918	27	27
9	919	30	30
9	920	30	30
9	921	30	30
9	922	30	30
9	923	32	32
9	924	34	34
9	925	35	35
9	926	35	35
10	1001	6	6
10	1002	11	11
10	1003	22	22
10	1004	22	22
10	1005	22	22
10	1006	22	22
10	1007	22	22
10	1008	22	22
10	1009	22	22
10	1010	22	22
10	1011	23	23
10	1012	23	23

Pig	Observation	tbs_sco (Orig)	tbs_sco (Inter)
10	1013	25	25
10	1014	25	25
10	1015	25	25
10	1016	29	29
10	1017	33	33
10	1018	35	35
10	1019	35	35