AN ANALYSIS OF DECOMPOSITION RATES ON OUTDOOR SURFACE VARIATIONS IN CENTRAL TEXAS

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AN ANALYSIS OF DECOMPOSITION RATES ON OUTDOOR

SURFACE VARIATIONS IN CENTRAL TEXAS

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I. INTRODUCTION

Forensic anthropologists are often faced with the task of establishing an accurate estimation of the time of death or postmortem interval (PMI) (Amendt et al. 2007). The estimation of PMI is crucial for ongoing criminal investigations in order to identify or eliminate suspects, or to reconstruct events and circumstances surrounding death. Forensic anthropologists are responsible for creating a biological profile from human skeletal remains, which includes age, sex, ancestry, stature, pathology and PMI. This type of information may aid investigators in linking a suspect to the victim and help to establish the credibility of statements made by witnesses (Amendt et al. 2007). An estimation of PMI may also be required for civil cases. For example, if the manner of death is natural, accidental or suicide, the PMI estimations may have judiciary implications in questions of insurance and inheritance (Greenberg and Kunich 2002).

There are various methods available to forensic anthropologists for providing an accurate PMI. Not all methods are as reliable as others however, and some methods have been out-dated and replaced by more recent and reliable techniques. Generally, a pathologist or medical examiner estimates the time since death in the early postmortem phases. Their assessments are based on the postmortem changes in soft tissues such as stiffness (rigor mortis), settling of blood (livor mortis), body cooling (algor mortis), and other stages of decomposition (Henβge et al. 1995). The latter soft tissue changes are subject to considerable variation, and diverse environments may cause different results. Therefore, some PMI assessments based solely on soft tissue appearance may be unreliable and markedly inaccurate (Amendt et al. 2007).

The decomposition process has inspired and motivated many studies over the years in the field of forensic anthropology (Bass 1997, Cahoon 1992, Clark et al. 1997, Galloway et al. 1989, Mann et al. 1990, Ritchie 2005, Rodriguez and Bass 1983). These previous research studies help explore various factors related to the condition of the body, health of the individual, or the surrounding environment and climate that may affect and alter the rate of decomposition and insect activity. For example, Amendt et al. (2007) state the age, health, cause of death, temperature, level of ventilation and air humidity, presence of clothing, and access of the body by insects and scavengers may directly alter the rate of decomposition. In addition to observational techniques, there are mathematical models or statistical tools that include all of the variables listed above for PMI estimations (Campobasso et al. 2001). Other authors claim using the temperature method or the chemistry of body fluid alone can produce maximum precision within a statistical confidence interval of 95% depending on the PMI, availability of equipment, circumstances of the death, and environment (Amendt et al. 2004, Campobasso et al. 2001, and Clark et al. 1997).

Finding deceased individuals in various outdoor settings on diverse surfaces may alter the rate of decomposition and, therefore, contribute to an inaccurate estimation of the PMI (Bass 1997, Mann et al. 1990). All environmental regions in the United States have different variables, such as temperature, humidity, elevation, species of scavengers, and the amount of precipitation and/or sunlight that may affect the rate of decomposition and accurate estimation of the PMI. It is very important to include local climatic conditions when scientifically analyzing the rate of decomposition of human remains (Galloway 1997). Previous research has shown differential rates of decomposition in diverse environments (Galloway 1997, Mann et al. 1990, and Reed 1958). Some of these environments receive a substantial amount of precipitation, like the state of Tennessee where research is performed at the Anthropological Research Facility (Mann et al. 1990). Autopsy and forensic anthropological reports regarding the arid region of the Arizona-Sonoran desert have determined rates of decomposition for that specific area (Galloway 1997). Compared to other regions in the United States, the climate and environment of central Texas is hot and relatively humid. During this study an average temperature of 26.77°C and an average humidity of 61.10% were recorded (Appendix C). There is a need to refine the criteria in order to determine a standard for the rate of decomposition and estimation of PMI for this area. Previous forensic anthropological research in areas of the United States has contributed good measures for decomposition that broadly encompasses wet and dry areas, but every environment displays a wide range of variables. Since the environment and climate plays a huge role in decomposition, it is crucial to measure all regions of the United States. This study will serve as an example for the variables present in central Texas and their effects on the rate of decomposition.

The goal of this research is to observe the rate of decomposition on various commonly occurring outdoor surfaces where human bodies are generally found in a forensic context. This research attempts to make a comparison between decomposition rates on various occurring outdoor surfaces, two of which are man-made (tarpaulin and concrete) and two naturally occurring surfaces (sand and gravel). These four experimental surfaces are compared to the rate of decomposition and insect colonization for a naturally occurring grassy foliage surface present in central Texas. The present research is important and intended to add to the existing knowledge of decomposition variables. This research project attempts to replicate homicide cases involving victim's bodies that are found on various outdoor surfaces. The objective of this research is to provide a decomposition study in an area where few studies have taken place and to provide a baseline of decomposition for central Texas using accumulated degree-days.

II. DECOMPOSITION AND STATEMENT OF PROBLEM

Stages and Categories of Decomposition

In the past, decomposition has generally been classified into five observational stages including, fresh (bloated), early decomposition (discoloration), advanced decomposition (first bone exposure), skeletonization (drying of the bones) and extreme decomposition (dry and weathered) (Carter et al. 2007, Galloway 1997, Megyesi et al. 2005, Payne 1965, Reed 1958, and Rodriguez and Bass 1983).

Stage One

The fresh stage is described as the time immediately following death when there is no discoloration or insect activity (Galloway 1997). When the subject displays severe bloating and blowflies (*Diptera:calliphoridae*) arrive and begin feeding on natural or wound openings of the subject, as well as laying eggs, which hatch into maggots that feed on the subject, then, the subject is classified in the bloated/early decomposition stage (Galloway 1997 and Payne 1965).

Stage Two

The subject displays discoloration from a natural flesh color to various shades of brown and green. Near the end of this stage the abdominal gases rupture and discoloration changes, known as marbling, from shades of brown and green to shades of black. Also, skin slippage and hair loss is present during this stage (Galloway 1997).

Stage Three

Next, during the active or advanced stage of decomposition the soft tissues produce sagging of the flesh, caving of the abdominal cavity, and extensive maggot activity. The subject and surrounding area is still very moist and some skeletal elements are exposed (Galloway 1997).

Stage Four

Then, during the dry stage of decomposition only dehydrated skin, cartilage, and skeletal elements of the subject remain. The bones may still retain some grease, and minimal moisture may be present (Payne 1965). By this stage most fly and maggot activity has ceased. At this point, mainly beetles (*Dermestidae:dermestid*) are present to feed on the remaining maggots and dried skin tissues.

Stage Five

Finally, during the dry/skeletonizaton stage the skeletal elements are fully exposed and begin the process of bleaching, exfoliation of the cortical bone, exposure of trabecular bone, and increased weathering and loss of minerals over time (Galloway 1997).

Although these decomposition stages are well researched and described, reliability is difficult to assess because of the many interacting variables. Most professional forensic practitioners possess their own subjective understanding and interpretation of the stages described. For example, one professional may consider a subject to be in the active decay stage of decomposition based on color, while another professional may interpret the color displayed differently and classify the subject in the early decomposition stage. This variation among professionals has created issues within the field of forensic anthropology when trying to create a standard for determining an accurate PMI estimation across various regions of the world.

In the past, decomposition has also been determined by the length of time a subject has been deceased and exposed to the surrounding elements (Megyesi et al. 2005). The problems with this dimensional method arise when subjects are found in different environments and across various regions of the world where temperature varies (Megyesi et al. 2005). Each environmental area offers a distinct set of variables that may affect the rate of decomposition and, consequently, cause an incorrect assessment or estimation of the PMI. For example, Galloway (1997) studied the rate of decomposition in the Arizona-Sonoran desert. This area of terrain consists of the northern Mexico state of Sonora and the southern portions of Arizona and California. The landscape consists of vegetation that is adapted to hot, arid conditions, and is dominated by cactus and creosote. Galloway (1997) discovered the fresh stage of decomposition generally lasts from the day of death through the seventh day of exposure. The early decomposition stage is classified as ranging from one week through as late as one month of exposure to the elements. The advanced decomposition stage is classified as one month or more since the time of death. These estimates of PMI operate as a standard for the environmental region in the Arizona-Sonoran desert, and it is probably applicable to areas with similar landscape and variables. However, these measures of the rate of decomposition would not be applicable to other regions. For example, western

Washington acquires considerably more rainfall each year, and consists of a plateau/mountain landscape with an abundance of evergreen trees (Shean et al. 1993).

Accumulated Degree-Days

Accumulated degree-days are defined as the heat energy units available to drive a biological process such as bacterial or fly larvae growth (Megysei et al. 2005). Accumulated degree-days are useful because the rate of decomposition will vary depending on the environment (Dent et al. 2004, Fiedler and Graw 2003, and Mann et al. 1990). Accumulated degree-days can be used to compensate for the differences in temperature (Vass et al. 1992 and Megyesi et al. 2005) across regions. To aid with the problem of establishing an accurate estimation of the rate of decomposition and PMI, Megyesi et al. (2005) proposed using observational decomposition stages and assigning each stage multiple categories with a numerical score. Megyesi and colleagues (2005) divide decomposition into four broad stages including, fresh, early decomposition, advanced decomposition, and skeletonization. During Megyesi et al.'s (2005) study the fifth stage of decomposition, extreme decomposition, was omitted. All four stages of decomposition are assigned to various categories to accurately describe each observational period. A point value system is then assigned to each category and starts at one point for the fresh stage and increases by one point for each progressive category. Next, Megyesi et al. (2005) divide the body into three sections because stages of decomposition do not apply equally to all parts of the body. For their study, part one consisted of the head and neck, including the cervical vertebrae. Part two consisted of the trunk, including the thorax, pectoral girdle, abdomen, and pelvic girdle. Part three consists of the upper and lower limbs, including the hands and feet. Then, the score of each of the three anatomical regions are combined to produce a total body score (TBS). For example, hypothetical case X is scored as follows: the head and neck, thorax, abdomen, pelvis, and limbs were all classified as the early stage of decomposition in the fourth category, which states discoloration and/or brownish shades particularly at the edges of the elements, drying of the nose, ears, and lips, resulting in a score of 5 + 5 +5 (Megyesi et al. 2005). Therefore, the TBS for this subject would be 15.

Table 1: Total body score

Body Section	**Stage of Decomposition**	**Score**
Head and Neck	Early Stage	5
Trunk	Early Stage	5
Limbs	Early Stage	5
Total Body Score	Early Stage	15

The lowest score a subject could receive is a 3, which would appear fresh in all regions, and the highest score a subject could receive is a 35, which would appear completely dry and fully skeletonized (Megyesi et al. 2005). The observed decompositional stage scores were then combined with the calculations of accumulated degree-days. The application of TBS is useful during decomposition studies because various elements of the body tend to decompose at uneven rates based on their composition. The total body score method was not applied during this research project, only the stages of decomposition and accumulated degree-days were recorded.

Combining the scores of the rate of decomposition with the method of accumulated degree-days (ADDs) may be the most accurate process to estimate the rate of decomposition and establish an accurate PMI (Carter et al. 2007). Accumulated degree-days are defined as a cumulative measure of temperature calculated as the mean daily temperature minus an index temperature, which is often 0ºC, summed over a period of time (Carter et al. 2007, Vass et al. 2008). Accumulated degree-days represent heat energy units available to propel a biological process such as bacterial or fly larvae growth (Megyesi et al. 2005). The base temperature is the temperature at which the biological process generally stops. The use of accumulated degree-days by forensic anthropologists when determining the rate of decomposition and PMI has become an increasingly crucial part of the practice. For example, the decomposition stage of advanced decay associated with a 68 kg human cadaver occurs at 400 and 1,285 ADDs, equally (Vass et al. 1992). Therefore, the average daily temperature of 25ºC in the summer would result in the onset of advanced decay after 16 days while an average daily temperature of 5ºC in the winter would result in an onset of advanced decay after 80 days (Carter et al. 2007). Accumulated temperature is one of the most important methods for defining climatic patterns (Ibrahim and Dennis 1982 and Richardson et al. 1974). A climatic region is composed of a number of meteorological elements; the use of one element eliminates overlapping and transition zones (Fairbridge 1967). The use of ADDs by forensic anthropologists aids in determining the rate of decomposition and an accurate estimation of PMI in various environments, as well as multiple seasonal variables (Megyesi et al. 2005).

Forensic Entomology

Forensic entomology is defined by Catts and Goff (1992) as the application of the study of insects and other arthropods to legal issues that inhabit decomposing remains to aid legal investigations. The application of ADDs by forensic anthropologists is based in applications from agriculture and entomology. The theory that the growth and development of many organisms is dependent on temperature dates as far back as the middle of the 18th century (Zalom et al. 1983), and it is still a useful concept in modern fields of anthropology, biology, entomology and agriculture. Organisms take a substantial amount of time to pass through successive stages at lower temperatures, and as the temperatures increase, development time progressively increases until the temperature becomes high enough to affect growth and development negatively (Zalom et al. 1983). The measure of accumulated temperature is known as physiological time, which provides a common reference for the development of organisms. The amount of heat required to complete a given organism's development does not vary (Zalom et al. 1983). It makes no difference whether the temperature is constant or fluctuating, the combination of temperature and time will always be the same. Physiological time is measured in degree days and one degree day is equal to one degree above the lower developmental threshold over 24 hours (Zalom et al. 1983). Forensic entomologists use ADDs to determine the average temperature required for insects to complete their growth development cycles. Using insects in death investigations is crucial because insects are most often the first to locate a decomposing subject. Blowflies will usually lay eggs on a recently deceased subject within the first few hours (Catts 1992). The arthropod fauna found in and around a subject changes in a rather predictable successional pattern as the rate of decomposition progresses (Catts and Goff 1992).

A forensic entomologist estimates PMI based on the insects showing the longest period of development. Although, this is assumed to reveal an estimation of the PMI provided the subject was exposed and conditions were suitable to insect activity at the beginning of the period (Catts 1991). This fact creates a problem with using forensic entomology to estimate an accurate PMI because the key assumption made is that insects, usually blowflies, will discover the subject soon after death (Catts 1992 and Hall 1991). Blowflies use decomposing material as a food source, as well as a place to lay their eggs, and develop larvae and pupae (Sumodan 2002). The blowflies are attracted to body fluids like urine, saliva, and fecal material protruding from natural orifices or open wounds (Sumodan 2002). The problem of accurately determining when the blowflies locate and colonize the decomposing material can be solved with the utilization of ADDs combined with forensic entomology, therefore ensuring an accurate estimation of PMI.

Forensic entomologists use a base temperature of 10ºC or 6ºC depending on the minimum temperature at which the fly species ceases to grow and develop (Catts 1990, Davidson 1944, Haskell et al. 1997, and Kamal 1958). Vass et al. (1992) state because of the level of salt concentrations in the human body, decomposition will occur down to 0ºC. On the other hand, Micozzi (1991) states no putrefaction will occur at temperatures less than 4ºC. However, it is unknown at what temperature the process of decomposition ceases (Megyesi et al. 2005).

Environment and Climate Variants

The study of forensic entomology and other factors that affect the rate of decomposition are very important; however additional factors may contribute to the estimation of the postmortem interval (Goff and Flynn 1991, Haglund et al. 1990, Haglund and Reay 1993, Schoenly et al. 1991, and Skinner et al. 1988). Influencing factors may be the ambient temperature, humidity or aridity, amount of rainfall, soil pH, clothing, burial type, burial and depth, animal and bird scavenging, and rodent gnawing and disarticulation, access of the body by insects, extent of perimortem trauma, size and weight of the body, the type of surface a subject is placed on, whether or not the subject has been embalmed, and general environmental conditions (Bass and Meadows 1990 and Mann et al. 1990). Also, the succession of postmortem change fluctuates regionally and among microenvironments within each locality. Galloway et al. (1989) observed and documented rapid bloating, and extensive mummification in the dry, arid desert environment of southern Arizona. Whereas, in hot and humid, tropical environments, skeletonization of a subject can occur within two weeks (Ubelaker 1989). Also, freezing and thawing retards the bacterial growth, therefore slowing the rate of decomposition (Micozzi 1986). The formation of adipocere in wet environments can lead to exceptionally long-term preservation of human remains (Mellen et al. 1993). Adipocere is defined by Cotton et al. (1987) as the "postmortem chemical alteration of normal adipose tissue rendering it firm, grayish white, and of wax like consistency." Adipocere acts as a protective layer preserving the overall anatomy of decomposing remains. Temperatures above 21°C promote the formation of adipocere and slow the decomposition process (Cotton et al. 1987).

Surface Variation

The type of surface on which a body is placed may affect the rate of decomposition and alter the PMI estimation. Research performed at the University of Tennessee-Knoxville has tested the rate of decomposition on a concrete surface compared to a ground surface (Mann et al. 1990). Each subject was placed on the surfaces at the same time therefore the subjects were exposed to the same elements and outdoor environment. The researchers found the bodies lying on the concrete usually, but not always, decomposed more slowly and became mummified more quickly than those on the ground surface (Mann et al. 1990). This may be due to the numbers of insects present on the ground surface in contrast to the concrete surface, but currently no verifiable explanation can be offered for the cause of this occurrence (Mann et al. 1990).

Reed (1958) conducted research concerning the rate of decomposition and various environmental habitats in Knoxville, Tennessee from May 7, 1951 through May 14, 1952. Reed randomly placed 61 dog carcasses in five wooded areas and four non-wooded areas to test the rate of decomposition in different surroundings and with various amounts of shade and sunlight. The wooded areas consisted of mixed woodlands with trees of medium density and the non-wooded areas consisting of open pasture with a few scattered medium-sized trees (Reed 1958). In addition to surface and sunlight variation, Reed (1958) tested the temperature of the subject compared to the outdoor temperature and the correlation with the rate of decomposition. He found the temperature of the subjects in the non-wooded areas changed more rapidly and fluctuated more widely than the temperatures of the subjects in the wooded areas. When outdoor temperatures fell between 10°C and 25°C the subject's temperature tended to be lower than the outdoor temperature, while at a higher temperature the subject's temperature tended to exceed the outdoor temperature. This research shows the immediate area surrounding a subject may have considerably different variables from the overall environment (Reed 1958). In addition to temperature, seasonal variations affected the insect population and activity, therefore altering the rate of decomposition during Reed's (1958) study. The majority of insects present during the Summer months, and are of smaller population size in the Fall and Spring months, and, as expected, the least number of insects occurs during the Winter months. The insect population is also affected by the variation of surfaces. In general, the insect populations are smaller around the subjects located in the non-wooded areas than those located in the wooded areas. During Reed's research (1958), the process of decomposition was completed more rapidly in the non-wooded areas than in the wooded areas.

Buried versus non-buried subjects also create a varied level of the rate of decomposition. Bodies lying on the surface of the ground tend to decay much more rapidly than bodies that have been buried beneath the soil (Mann et al. 1990). In addition, the depth of burial also plays an essential role in the rate of decomposition. Subjects that are buried to a depth of 0.3 m or 0.6 m may skeletonize in a few months to a year or more (Mann et al. 1990). On the other hand, subjects that are buried at 0.9 m or 1.2 m may take many years to complete the process of decomposition to reach the stage of skeletonization. These examples show that the immediate area surrounding a subject influences the rate of decomposition, and should be taken into consideration when estimating the PMI.

Current Research

The objective of this research project is to provide a decomposition study in an area where few studies have taken place and to provide a baseline of the stages of decomposition for central Texas using accumulated degree-days. The present research is important and intended to add to the existing knowledge of decomposition variables discussed within this chapter.

III. MATERIALS AND METHODS

The Environment

This research was conducted in central Texas, at the Forensic Anthropology Research Facility located on Freeman Ranch near San Marcos, Texas during the summer months of July, August, and September of 2008. Freeman Ranch is located in climate zone 30 in the hill country of central Texas. This region consists of rolling hills, limestone rocks and boulders, and a thin layer of topsoil. Freeman Ranch (longitude -98°W, latitude 30°E, Elevation 272 m) has outside high temperatures over 38°C and lows in the teens during the summer months in which this research took place. Freeman Ranch is a 4,200 ha (1 ha = 10,000 square meters or 2.5 acres) research area owned by Texas State University-San Marcos (Heinsch et al. 2004). It is located on the eastern Edwards Plateau in central Texas and overlies the recharge area of the Edwards Aquifer. Most of the ranch is occupied by upland habitats with dominant species that include Plateau Live Oak (*Quercus virginiana* var. *fusiformis*), Ashe juniper (*Juniperus ashei*) clusters interspersed in perennial grasslands (Heinsch et al 2004). Due to overgrazing and fire suppression, there is woody encroachment by Ashe juniper. The vegetation type is classified as grassland in transition to Ashe juniper-dominated woodland or woody savannas (Heinsch et al. 2004).

Figure 1: Day Zero. Photograph of the research site at the Forensic Anthropology Center at Texas State University located on Freeman Ranch near San Marcos, Texas before the various surfaces were distributed.

Figure 2: Day One. Photograph of the specimens the initial day of placement.

Materials

Sample

Throughout this research project, domestic pigs (*Sus scrofa*) were used as a substitute for human cadavers. Pigs are often used as a substitute for human subjects in decomposition studies due to the similarities in intestinal flora, skin, tissue and muscle structure, as well as the progression of decomposition (Anderson and VanLaerhoven 1996, Campobasso et al. 2001, Goff 1993, Hewadikaram and Goff 1991, Micozzi 1991, Shean et al. 1993). Micozzi (1991) researched the decay rates of various animals and found domestic pigs to be the most suitable replacement for humans. Although human cadavers are favorable for their direct application to actual forensic cases, they were unavailable at the time of this research project.

Five pigs averaging a weight of 48.2 kg (106.2 lbs) were used as proxy to approximate the actual weight of human cadavers. Although it is apparent that specimens with an average weight of 48.2 kg are relatively small human substitutions, they were the largest subjects available during the time this research was conducted.

Table 2: The actual weight of each specimen and the combined average weight of all five specimens.

Specimen	**Actual Weight**
Pig 1	47.6 kg
Pig 2	46.7 kg
Pig 3	49.9 kg
Pig 4	48.5 kg
Pig 5	48.1 kg
Combined average weight	48.2 kg

The sample (n = 1 subject for each of the 5 surfaces) was purchased from a pig breeder and transported from a farm in New Braunfels, Texas on July 19, 2008. The pigs were obtained during the time of year when the farmer routinely culls his herds. The pigs were similar in size and weight in order to minimize unnecessary variables (Table 2). The pigs were weighed before they were culled to ensure similar size. All of the pigs were placed in full sunlight on the various designated surfaces on the same day and at the same time.

Surfaces

All materials used were purchased from a local hardware store. Pig 1 was placed on the naturally occurring surface at Freeman Ranch. A Duraworx® brand 5 mil 2.7 m by 3.7 m tarpaulin was used to create the tarpaulin surface for pig 2. Six 30.5 cm Oldcastle® square, grey concrete stepping stones, measuring 30.5 cm by 30.5 cm by 4.8 cm, were used to create the concrete surface for pig 3. Three stepping stones were placed alongside the other three stepping stones to create a rectangular surface large enough for pig 3. Two 18.1kg bags of Scotchman's® paver sand was laid on the ground to create the sand surface for pig 4. Two 0.15 cubic m of Rock City® river rock was laid on the ground to create the gravel surface for pig 5.

Cages

The pigs were enclosed in an area at the ranch completely surrounded by a chain link fence. They were also covered and secured by five very strong, thick galvanized steel link cages constructed from horse security panel wire cages which made the carcasses available to insects, but prevented larger animals and birds from scavenging the remains. The steel cages measured 91.4 cm wide, 182.9 cm long and 45.7 cm high, with

5.0 x 10.2 cm holes and a gauge strength of 6, which is 0.51 cm thick wire. The cages were secured over the specimens using metal tent stakes and large rocks. The cages were removed daily to record the progression of decomposition, take photographs, and document the insects present. Cages were re-secured after observations and photographs were completed for the day.

Temperature Data

The outdoor high and low temperature was obtained daily, and recorded via the Texas State Weather Station located on Freeman Ranch. The outdoor high and low temperatures are considered very accurate because the weather station is immediately adjacent to the research site.

Photography Equipment

An Olympus® FE-340 camera was used for all photographs documented throughout the course of this research project. The camera has 8.0-megapixel resolution assuring a clear, detailed record of the specimens as well as the insects present.

Data Collection Methods

The five pigs were placed on various surfaces, exposed to full sunlight, that either occur commonly in outdoor settings or are artifacts associated with the concealment of a body: [1] control; foliage surface present at Freeman Ranch, [2] tarpaulin, [3] concrete, [4] sand, and [5] gravel. Each pig specimen was labeled pig 1 through pig 5. Pig 1 was placed on the naturally occurring foliage surface present at Freeman Ranch. The rate of decomposition of pig 1 served as the control specimen for the standard rate of decomposition in this type of region in a hot and humid environment (average temperature 26.77°C and average humidity 61.10%).

Data Collection

All subjects were observed daily from day one until day twelve when insect activity had significantly decreased and the decomposition had slowed. The colonization of flies and maggots is one of the most crucial aspects in aiding the process of decomposition. From day fourteen until day twenty-three all specimens were observed once every three days showing very little change and minimal insect activity. Observations continued once a week from day thirty-three through day sixty-nine, which was the last day of observation (Appendix A). Weather data, observations, and photographs were taken regularly to document the stages of decomposition and the insects present.

Placement

Pig 1 was placed on the naturally occurring foliage surface at Freeman Ranch and served as the control specimen for the area. Pig 2 was placed on the waterproof tarpaulin surface. Pig 3 was placed on the concrete slab surface. Pig 4 was placed on the sand surface. Pig 5 was placed on the gravel surface. On day zero, all of the specimens were classified into stage one, the fresh stage of decomposition. No insect activity was observed on any of the specimens the initial day of placement.

Day Zero – July 12, 2008

Research began on July 12, 2008 with the distribution of the materials used to create the various outdoor surface micro environments. The surface was raked and cleared of all naturally occurring vegetation before the artificial surfaces were distributed.

Day One – July 19, 2008

The pigs were obtained from the farmer, transported to Freeman Ranch, and placed on the surfaces on July 19, 2008. Time of death was 11:45 am to 11:55 am and the specimens arrived at the research facility at 12:25 pm. The pigs were removed from individual Rubbermaid® Roughneck 11.36 decaliter storage containers and placed on the surfaces from 12:30 pm to 12:45 pm. Photographs and observations were recorded from 12:45 pm to 1:15 pm. The steel cages were placed and secured over the specimens from 1:15 pm to 1:30 pm to ensure protection from scavengers.

Accumulated degree-days (ADDs)

For this research, a more quantitative approach was utilized to record the post mortem interval (PMI). The outdoor high and low temperature was obtained daily, and recorded via the Texas State Weather Station located on Freeman Ranch. In order to calculate accumulated degree-days the temperature was obtained daily, and the average of the maximum and minimum air temperature for each day was documented (Appendix C). Similar to the study preformed by Megysei et al. (2005) ADDs were added cumulatively until the experiment ceased. The high and low temperature were added together then divided by two to obtain the average temperature for the day. In order to calculate ADDs the average temperatures were added together (Table 3).

Table 3: Accumulated degree-days

Day/Month	Day	High (C°)	Average (C°)	Low (C°)	ADDs
19-Jul	1	36.80	28.26	19.71	28.26
20-Jul	2	37.27	29.43	21.58	57.69

Average: 36.80 + 19.71 = 56.51
56.51/2 = 28.26
ADDs: 28.26 + 29.43 = 57.69

Stages of Decomposition

Generally, accumulated degree-days and the stages of decomposition are combined to gain a more accurate assessment of the PMI. Stages of decomposition were divided into five categories, which follow a sequenced order from one stage to the next (Micozzi 1991, Payne 1965, Reed 1958, Rodriguez 1983). Anthropologists utilize their knowledge and experience of their particular environmental region to produce an estimate of PMI from the stages of decomposition (Bass 1997, Mann et al. 1990, Sledzik 1998).

For this research project, the rate of decomposition was scored using the Galloway et al. (1989) method, which classifies the stages of decomposition into five major descriptive categories: [1] fresh, [2] early decomposition, [3] advanced decomposition, [4] skeletonization, and [5] extreme decomposition. Within each of these stages there are secondary descriptive categories, which do not imply a sequence of events, but describe the overall condition and appearance of the remains (Galloway 1997). The five categories of decomposition are used to describe the specific stages concerning the appearance and general characteristics of the decaying remains (Megysei et al. 2005). For this study, it was necessary to modify Galloway's (1997) approach because originally, decomposition stages were divided into five broad categories including, fresh, early decomposition, advanced decomposition, skeletonization, and decomposition of skeletal material (Galloway 1997). The only specimen to reach the fifth stage of decomposition was pig 1, the control subject. Due to lack of time, the fifth stage has not been included for pig 2 through pig 5.

Table 4: Categories and Stages of Decomposition. (From Galloway 1997:141)

A. Fresh
   1. Fresh, no discoloration or insect activity
   2. Fresh burned

B. Early Decomposition
   1. Pink-white appearance with skin slippage and some hair loss
   2. Gray to green discoloration, some flesh relatively fresh
   3. Discoloration to brownish shades particularly at fingers, nose and ears; some flesh still relatively fresh
   4. Bloating with green discoloration
   5. Post bloating following rupture of the abdominal gases with discoloration going from green to dark
   6. Brown to black discoloration of arms and legs, skin having leathery appearance

C. Advanced Decomposition
   1. Decomposition of tissues producing sagging of the flesh, caving in of the abdominal cavity, often accompanied by extensive maggot activity
   2. Moist decomposition in which there is bone exposure
   3. Mummification with some retention of internal structures
   4. Mummification of outer tissues only with internal organs lost through autolysis or insect activity
   5. Mummification with bone exposure of less than one half the skeleton
   6. Adipocere development

D. Skeletonization
   1. Bones with greasy substances and decomposed tissue, sometimes with body fluids still present
   2. Bones with desiccated tissue or mummified tissue covering less than one half the skeleton
   3. Bones largely dry but still retaining some grease
   4. Dry bone

E. Extreme Decomposition
   1. Skeletonization with bleaching
   2. Skeletonization with exfoliation
   3. Skeletonization with metaphyseal loss with long bones and cancellous exposure of the vertebrae

IV. RESULTS

All of the specimens were classified into stage two of decomposition known as the bloated/early stage on day two, July 20, 2008. Putrefaction was apparent in all of the pigs, which was likely due to the warm summer weather of central Texas. Beginning stages of decomposition such as discoloration, bloating, and the secretion of a slight odor were present on all specimens. Very few flies were observed on the specimens, although fire ants were abundant mainly around the foam substance, protruding from the mouths of the specimens. Later on day two, all of the specimens were in full rigor and some of the abdominal cavities had ruptured in order to release the gases and fluids produced by the decomposition process of the body.

Control Surface: Pig 1

Pig 1, the specimen located on the control surface, illustrates the baseline for the decomposition process in the summer in central Texas. The log of observations in Appendix A presents the decomposition process, insects, and maggots present on the specimen. Overall, pig 1 was the only specimen to reach the fifth stage of decomposition. Pig 1 was the fastest specimen to reach and complete all the stages of decomposition. Pig 1 was in the fresh stage for one day, followed by the early stage of decomposition lasting until the morning of day four (ADDs 58). Next, pig 1 was in the advanced stages of decomposition from the evening of day four to day seven (ADDs 116), followed by the skeletonization process from day eight to day fourteen (ADDs 227. Finally, the specimen reached the last stage of decomposition, extreme decomposition, from day seventeen through the last day of observation, day sixty-nine (ADDs 494).

Table 5: Pig 1 - Grass Surface (Appendix B)

Stage of Decomposition	**Accumulated Degree-Days**
Stage 1: Fresh	28-58
Stage 2: Early Decomposition	58-116
Stage 3: Advanced Decomposition	116-198
Stage 4: Skeletonization	198-405
Stage 5: Extreme Decomposition	405-1,856

<u>Modified Surfaces: Pig 2 through Pig 5</u>

Pig 2, the specimen located on the tarpaulin surface, appeared to be the fastest during the beginning stages of decomposition although it ended as one of the slowest specimens to complete the remaining stages. It never reached the final stage of decomposition. Pig 2 was in the fresh stage for one day, followed by the early stage of decomposition from the morning of day two through the morning of day four (ADDs 58). Pig 2 began the advanced decomposition stage the evening of day four through day nine (ADDs 227). Pig 2 progressed from the early stage to the advanced stage of decomposition but then slowed during the skeletonization stage lasting from day nine through day sixty-nine (ADDs 286). By casual visual observation, pig 2 attracted the most maggots early on, but the tarpaulin surface did not allow the liquids being released from the body to seep into the ground. Therefore, the maggots could not survive in the wet environment. The fewer the number of maggots present on a specimen, the longer it will take to complete the decomposition process. Pig 2 did not reach the extreme decomposition stage. Overall pig 2 was the second slowest specimen to decompose.

Table 6: Pig 2 - Tarpaulin Surface (Appendix B)

Stage of Decomposition	**Accumulated Degree-Days**
Stage 1: Fresh	28-58
Stage 2: Early Decomposition	58-116
Stage 3: Advanced Decomposition	116-256
Stage 4: Skeletonization	256-1,856

Pig 3, the specimen located on the concrete surface, was by far the slowest specimen to complete the decomposition process. This result supports the existing research by Mann et al. (1990) that bodies lying on concrete usually decompose more slowly and become mummified more quickly than those on the ground. Pig 3 was in the fresh stage for one day, followed by the early stage of decomposition from the morning of day two through day six (ADDs 58). Pig 3 began the advanced decomposition stage on day seven and continued until day nine (ADDs 198), then entered the skeletonization stage from day ten through day sixty-nine (ADDs 286). Pig 3 had the least amount of observed fly activity, and was the last specimen to be colonized with maggot activity. The reasoning for this can only be contributed to the surface type because all other elements, such as location and temperature, were the same when compared to the other specimens. Pig 3 did not reach the extreme decomposition stage and overall was the slowest specimen to decompose.

Table 7: Pig 3 - Concrete Surface (Appendix B)

Stage of Decomposition	**Accumulated Degree-Days**
Stage 1: Fresh	28-58
Stage 2: Early Decomposition	58-169
Stage 3: Advanced Decomposition	169-256
Stage 4: Skeletonization	256-1,856

Pig 4, the specimen located on the sand surface, and pig 5, the specimen located on the gravel surface were very similar throughout the entire process of decomposition. Pig 4 and pig 5 were in the fresh stage for one day, followed by the early stage of decomposition from the morning of day two through day five (ADDs 58). Pig 4 and pig 5 began advanced decomposition on day six and continued until day ten (ADDs 169), then entered the skeletonization stage from day eleven through day sixty-nine (ADDs 315). Throughout the research project, pig 4 was colonized by the most fire ants possibly due to their natural environment in loose soil. Since fire ants feed on maggots, they may also contribute to the slower rate of decomposition (Mann et al. 1990).

Table 8: Pig 4 and Pig 5 - Sand Surface and Gravel Surface (Appendix B)

Stage of Decomposition	**Accumulated Degree-Days**
Stage 1: Fresh	28-58
Stage 2: Early Decomposition	58-144
Stage 3: Advanced Decomposition	144-286
Stage 4: Skeletonization	286-1,856

Pig 1 (control), pig 4, (sand) and pig 5 (gravel) were placed on surfaces that would commonly occur in natural outdoor settings. These three specimens completed the decomposition process more quickly than pig 2, tarpaulin surface, and pig 3, concrete surface, which are man-made surfaces. The accessibility of the liquids being released from the bodies on the natural surfaces in order to penetrate the soil may have impacted the overall rate of decomposition when compared to the man-made surfaces. The maggots colonized pig 2, the tarpaulin surface, quickly but did not successfully survive in the liquid that was unable to disperse into the ground and thus pooled around the specimen. A large aspect of the decomposition process and soft-tissue destruction is the result of insect larvae consumption (Mann et al. 1990). Pig 3, the concrete surface, was the slowest to decompose possibly because the flies and maggots were unable to access the posterior side of the specimen due to the hard concrete surface.

<u>Description of Variables Observed</u>

Blowflies (*Diptera calliphoridae*) – Blowflies were scarce during the initial day of placement but extreme fly activity was visually observed from day two through day eight and decreased throughout the remainder of this research project. Several generations of flies were present on all subjects (Table 9-13).

Beetles (*Dermestes lardarius*) – Flesh-eating beetles were observed on the specimens as early as day eight through as late as day fifty-six (Table 9-13).

Marbling – Marbling describes the discoloration of the soft tissue when veins and arteries become visible due to bacterial action of the decomposition process. During this study, the onset of marbling was present by day two or three on all specimens (Table 9-13).

Mummification – Mummification is the drying and hardening process of the soft tissue. The soft tissue becomes darker and takes on a leathery appearance. Mummification was present on all specimens by day eight or nine (Table 9-13).

Stages of Decomposition – The control specimen was the only subject to complete stages one through five of the decomposition process described by Galloway (1997). The stages can be found in Table 4 or in the "Categories and Stages of Decomposition" (Galloway 1997:141) (Table 9-13).

Observation of Variables

Blowfly Activity

Fly activity was present on all specimens, although maggot colonization occurred at different times. No flies were observed on the initial day of placement which is relatively unusual. Flies are generally present within minutes of the exposure of a decaying specimen. Few flies were present the morning of day two and increased rapidly throughout the evening of day two. Fly activity was abundant by the end of day two through day eight. Minimal fly activity was observed throughout the remainder of this research project.

The amount of fly activity was not consistent on all of the specimens. Pig 1, pig 2, pig 4, and pig 5 had no flies present on day one, few flies present on the morning of day two, multiple flies present the end day two through day eight, and few flies from day nine until the end of this research project. Pig 3 (concrete surface) had no flies present on day one, few flies present on day two through day four, multiple flies present day five through day seven, and few flies present day eight until the end of this research project. The slowed process of decomposition observed on pig 3 which is more than likely due to the type of surface causing the delay in fly colonization.

Beetle Activity

Flesh-eating beetles were present on all specimens at different times due to the altered rate of decomposition by the various surface types. Pig 1, pig 2, pig 4 and pig 5 had similar timing of beetle colonization and departure. Pig 1 (control surface) had beetles present on day eight through day forty-two. Pig 2 (tarpaulin surface) had beetles present on day ten through day fifty-six. The departure of beetles on pig 1 was more than likely due to the fast decomposition of the remaining soft tissues. Pig 3 (concrete surface) did not have beetles present until day seventeen through day sixty-nine due to the slower process of decomposition.

Stages of Decomposition

Fresh Stage

All five of the subjects were classified in the fresh stage of decomposition on day one and all ceased on the morning of day two. The fresh stage of decomposition is described as a specimen with no discoloration or insect activity (Galloway 1997).

Early Decomposition Stage

All five of the subjects were classified in the early decomposition stage on the morning of day two, although the early decomposition stage lasted longer for some of the specimens. Overall, pig 1 and pig 2 began the decomposition process the most quickly and completed the early decomposition stage by the evening of day four. Pig 3 was in the early stage of decomposition for the longest period of time when compared to the other specimens which lasted until day six. The stages of decomposition for pig 4 and pig 5 were very similar throughout the entire research project. Pig 4 and pig 5 completed the early decomposition stage by day five. Maggot activity was more extensive on the specimens that completed the early decomposition the fastest.

Advanced Decomposition Stage

Pig 1, the control surface, specimen entered the advanced decomposition stage on the evening of day four and continued through day seven. Pig 2 also entered the advanced decomposition stage on the evening of day four but lasted until day nine. Pig 3 did not begin the advanced decomposition stage until day seven and lasted until day nine.

Pig 4 and pig 5 started the advanced decomposition stage on day six and continued until day ten.

Skeletonization Stage

Pig 1 reached skeletonization by day eight and continued through day fourteen. Pig 2 and pig 3 began skeletonization on day ten and lasted until the completion of this research project on day sixty-nine. Pig 4 and pig 5 entered the skeletonization stage on day ten through day sixty-nine.

Extreme Decomposition Stage

Pig 1, the control surface, subject was the only specimen to reach the extreme decomposition stage. Extreme decomposition stage began on day seventeen and continued throughout the duration of this research project. Pig 1 showed evidence of drying and bleaching of the skeletal material on day twenty-three. Bleaching (lightening in color), exfoliation (chipping) and weathering (deterioration) of the skeletal material was observed on day fifty-six through the end of this project.

V. DISCUSSION

The objective of this research project was to observe how the type of surface on which an individual is found will impact the rate of decomposition. This research demonstrates that the surface on which a body lies is an important variable that should be considered when estimating PMI from decomposition rates. All specimens were exposed to the same elements, such as weather, precipitation, temperature, location and treatment. The only difference from specimen to specimen was the type of surface they were placed upon. Pig 1, the control subject, was the fastest to decompose and the only specimen to reach the final stage of extreme decomposition. Pig 2 through pig 5 possessed enough remaining tissue for mummification to occur which prolonged the skeletonization stage of decomposition.

The delayed insect and maggot colonization of pig 3 caused it to be the slowest specimen to decompose. Due to the hard concrete surface flies and maggots were unable to access the posterior side of the specimen, this, in turn, resulted in a low number of insects and slowed the overall process of decomposition. This result is consistent with the existing research by Mann et al. (1990) where bodies were placed on concrete and ground surfaces at the same time while exposed to the same elements. Mann et al. (1990) also found bodies lying on concrete usually (but not always) decay more slowly and become mummified more quickly than those on the natural ground surface. The maggots present on pig 2 did not survive in the liquid being released from the specimen which pooled around the body on the tarpaulin surface. The lack of successful maggot activity due to the surface type directly affected the rate of decomposition.

This research is an example of the decomposition process in central Texas during the hot (26.77°C), relatively humid (61.10%) summer months of July, August, and September in 2008 (Appendix C). Although, the climate of central Texas possesses notable humidity, it is not enough to completely prevent the mummification process. Various environments across regions are important to explore concerning the variables that may affect the rate of decomposition. It is very important to note the differences in environments and variables because the results of this study significantly differ from those found by Galloway et al. (1997). Galloway et al. (1997) focused on the rate of decomposition in arid environments where data were gathered based on the key elements found in climates located in Arizona-Sonoran Desert area. During Galloway et al. (1997)'s study researchers classified remains in the fresh stage of decomposition from the initial day of placement to the seventh day. During the current research project none of the specimens were classified in the fresh stage of decomposition after day 1, they had all progressed to the early stage of decomposition by the afternoon of day 2. In addition, the majority of the cases examined during Galloway et al. (1997)'s study recorded the early decomposition stage as lasting from one week to one month. During this study the specimens completed the early stage of decomposition as early as the morning of day 4 (pig 1 and 2) and as late as day 6 (pig 3). When the results from the current study from central Texas are compared to those of the results from the Arizona-Sonoran Desert area concerning the rate of decomposition it is evident that the environment, climate and variables contribute to the amount of time it takes a specimen to complete each decomposition stage. This type of knowledge is crucial for investigators and professionals estimating accurate PMI.

When observing the results from pig 3, they are consistent with those found by Mann et al. (1990) who performed a decomposition study at the University of Tennessee-Knoxville. During Mann et al. (1990)'s study researchers found the rate of decomposition to be generally slower on a concrete surface compared to a natural ground surface. During the current research project it was also found that the decomposition process was slowed due to the hard concrete surface in which the individual was placed.

The state of Texas occupies various unique climates and environments where additional decomposition studies are needed. Data such as these are important to consider when establishing a PMI due to the many factors affecting the rate of decomposition and an accurate estimation. Future research and data are needed in various environments to ensure the consideration of all variables possibly speeding or slowing the process of decomposition.

Limitations

Several limitations were present during this research project. First, the substitution of pigs for human cadavers is not favorable but continues to be a viable alternative option available for researchers. The sample size was limited and this type of research would benefit from additional replication trials and a larger sample size. Also, the sample was not statistically valid and this study should be replicated using a larger sample size for one specific surface to ensure an accurate estimation of the rate of decomposition in each condition. Supplementary surface types or other environments other than the five explored here need to be investigated as well to determine their impact on the rate of decomposition and insect activity. During the current study specimens were placed above ground in full sunlight. It would be beneficial to explore the rate of decomposition when an individual is placed in a shallow burial and above ground to observe the differences in decomposition. In addition, it would be valuable to observe the rate of decomposition when individuals are found in a forested area with shade compared to individuals found in an open area with full sunlight.

Time also played a role in limiting the current research project because pig 2 through pig 5 experienced a prolonged skeletonization stage due to mummification. Due to lack of time, the research project ended before pig 2 through pig 5 could reach the extreme decomposition stage. A replication of this research project during the same summer months in central Texas would be beneficial in order to observe the same or varying results. The final limitation of this decomposition study is that it was performed in the climate of central Texas, which was one of the goals of the research project. If this study were performed in another region or during different seasons the results may be very different. Although it is likely the surface would impact the rate of decomposition in any situation.

VI. CONCLUSIONS

The goal of this research project was to observe the rate of decomposition on various commonly occurring outdoor surfaces in central Texas, where bodies in real forensic cases are often found. The rate of decomposition was longer for the experimental surface subjects (tarpaulin, concrete, sand and gravel) than the control surface subject (grass). While the experimental subjects (pig 2 through pig 5) ceased at the skeletonization stage of decomposition, the control specimen (pig 1) reached the final stage of extreme decomposition. The experimental subjects eventually would have reached the final stage of extreme decomposition but the study was ended before the specimens had progressed enough to be classified into that stage of decomposition. The results demonstrate the major differences between the control subject and the experimental subjects were caused by the different surface types. In general, rates of decomposition are faster on natural earth surfaces, and slower on other man-made surfaces. The slower decomposition observed on man-made surfaces may be due to the lack of successful insect colonization. Consequently, the rate of decomposition is altered based on the type of surface on which the specimen is found and the ability for insects to colonize and survive on the subject. Finally, it is clear that the rate of decomposition is influenced by the surface on which the body lay, but the exact rate on human bodies has yet to be determined.

The objective of this research project was to provide a decomposition study in an area where few previous studies have taken place. In addition to providing a baseline for the rate of decomposition in central Texas using accumulated degree-days. With the use of this research, more accurate PMI estimations may be possible, but the exact rate on human bodies has yet to be determined. Future research projects using human bodies on various outdoor surfaces will allow for more accurate and realistic results that can be applied to forensic cases. This type of research would further our understanding of the rate of decomposition and how the ground surface affects the rate of decomposition and insect colonization.

APPENDIX A

Table 9: Control results and observations of the decomposition process and insect activity of Pig 1

Day	Observations
1 – Fresh July 19, 2008 – 1:15 pm	No flies present Foaming at the mouth Livor mortis
2.1 – Early Decomposition July 20, 2008 – 8:30 am 2.2 – Early Decomposition July 20, 2008 – 6:00 pm	Few flies present on head, eyes, and anal cavity Foaming at the mouth Fire ants present on foam Green discoloration and blistering of skin on abdominal cavity Slight odor Beginning of bloating stage Livor mortis Rigor mortis Multiple flies present Second most flies present Rupture of abdominal gases Livor mortis subsiding Rigor mortis No marbling
3 – Early Decomposition July 21, 2008 – 11:00 am	Maggot activity inside mouth Large maggots Marbling present
4.1 – Early Decomposition July 22, 2008 – 9:00 am 4.2 – Advanced Decomposition July 22, 2008 – 2:00 pm	Extensive maggot activity on mouth, face, head, neck, and underneath the body cavity Discoloration of soil and vegetation around body cavity Extensive maggot activity Exposure of cranium Sagging of flesh
5 – Advanced Decomposition July 23, 2008 – 2:00 pm	Extensive maggot activity Exposure of zygomatics, eye orbits, and left humerus Sagging of flesh Caving of abdominal cavity Fastest decomposition thus far

Table 9-Continued: Control results and observations of the decomposition process and insect activity of Pig 1

6 – Advanced Decomposition July 24, 2008 – 11:30 am	Extensive maggot activity Exposure of cranium, mandible, left scapula, humerus, and eight ribs Sagging of flesh
7 – Advanced Decomposition July 25, 2008 – 1:00 pm	Extensive maggot activity on and around the body cavity Maggot mass on vertebral column Complete exposure of the cranium, mandible, left scapula, humerus, and eight ribs Partial exposure of the left radius, ulna, os coxa, femur, tibia, fibula, and vertebrae
8 – Skeletonization July 26, 2008 – 10:00 am	Few maggots present Few beetles present Complete exposure of left femur, tibia, and fibula Partial exposure of the left radius, ulna, os coxa, and vertebrae
9 – Skeletonization July 27, 2008 – 7:30 pm	No maggot activity Majority of flesh decomposed Mummification of outer tissues Beetles present
10 – Skeletonization July 28, 2008 – 5:00 pm	Mummification Bones retaining some grease Beetles present
11 – Skeletonization July 29, 2008 – 6:30 pm	Mummification Bones retaining some grease Beetles present
12 – Skeletonization July 30, 2008 – 7:30 pm	Mummification Drying of bones Beetles present
14 – Skeletonization August 1, 2008 – 5:00 pm	Mummification Drying of bones Beetles present
17 – Extreme Decomposition August 4, 2008 – 6:00 pm	Drying and bleaching of exposed skeletal material Beetles present
20 – Extreme Decomposition August 7, 2008 – 7:30 pm	Drying and bleaching of exposed skeletal material

Table 9-Continued: Control results and observations of the decomposition process and insect activity of Pig 1

23 – Extreme Decomposition August 11, 2008 – 4:00 pm	Drying and bleaching of exposed skeletal material Beetles, centipedes, and dragon flies present Slight odor still present
33 – Extreme Decomposition August 21, 2008 – 11:00 am	Drying and bleaching of exposed skeletal material Animal scavenged back legs and feet Beetles and centipedes present Almost fully skeletonized
42 – Extreme Decomposition August 29, 2008 – 12:00 pm	Drying and bleaching of exposed skeletal material Animal scavenged front legs and feet Beetles present Almost fully skeletonized
56 – Extreme Decomposition September 12, 2008 – 5:00 pm	Drying, bleaching, and exfoliation of exposed skeletal material
69 – Extreme Decomposition September 25, 2008 – 3:00 pm	Drying, bleaching, exfoliation, and weathering of exposed skeletal material Animal scavenging Completely skeletonized Disarticulation of skeleton

Table 10: Tarpaulin surface results and observations of the decomposition process and insect activity of Pig 2

Day	**Observations**
1 – Fresh July 19, 2008 – 1:15 pm	No flies present Foaming at the mouth
2.1 – Early Decomposition July 20, 2008 – 8:30 am	Few flies present Foaming at the mouth Fire ants present on foam Greenish, blue, black discoloration of abdominal cavity No blistering of skin Slight odor Beginning of bloating stage Livor mortis Rigor mortis
2.2 – Early Decomposition July 20, 2008 – 6:00 pm	Multiple flies present Most flies present Fly mass under back legs Fire ants present Rupture of abdominal gases Release of bodily fluids gathered on tarpaulin surface Livor and rigor mortis subsiding Marbling present
3 – Early Decomposition July 21, 2008 – 11:00 am	Multiple flies present Most present in mouth Maggot mass in mouth, on head, and under body cavity along the vertebral column Liquid and gases releasing from natural and wound orifices
4.1 – Early Decomposition July 22, 2008 – 9:00 am	Extensive maggot activity on entire specimen Most amount of maggots present Maggots increases and underneath tarpaulin Maggots in fluids pooled on the tarpaulin No fire ants
4.2 – Advanced Decomposition July 22, 2008 – 2:00 pm	Extensive maggot activity Sagging of flesh

Table 10-Continued: Tarpaulin surface results and observations of the decomposition process and insect activity of Pig 2

5 – Advanced Decomposition July 23, 2008 – 2:00 pm	Extensive maggot activity Partial exposure of vertebral column Sagging of flesh Caving of abdominal cavity
6 – Advanced Decomposition July 24, 2008 – 11:30 am	Extensive maggot activity Sagging of flesh
7 – Advanced Decomposition July 25, 2008 – 1:00 pm	Moderate maggot activity Partial exposure of the cranium, mandible, vertebral column, left os coxa, and tibia
8 – Advanced Decomposition July 26, 2008 – 10:00 am	Moderate maggot activity Partial exposure of the cranium, mandible, vertebral column, left os coxa, and tibia
9 – Advanced Decomposition July 27, 2008 – 7:30 pm	Moderate maggot activity Onset of mummification of outer tissues Partial exposure of the cranium, mandible, vertebral column, left os coxa, and tibia
10 – Skeletonization July 28, 2008 – 5:00 pm	Few maggots present Mummification Bones retaining some grease Beetles present
11 – Skeletonization July 29, 2008 – 6:30 pm	Mummification Bones retaining some grease Beetles present
12 – Skeletonization July 30, 2008 – 7:30 pm	Mummification Drying of bones Beetles present
14 – Skeletonization August 1, 2008 – 5:00 pm	Mummification Drying of bones Beetles present
17 – Skeletonization August 4, 2008 – 6:00 pm	Mummification Drying of bones Beetles present
20 – Skeletonization August 7, 2008 – 7:30 pm	Mummification Drying and bleaching of exposed skeletal material Beetles present

Table 10: Tarpaulin surface results and observations of the decomposition process and insect activity of Pig 2

23 – Skeletonization August 11, 2008 – 4:00 pm	Drying and bleaching of exposed skeletal material Beetles, centipedes, and fire ants present Slight odor still present
33 – Skeletonization August 21, 2008 – 11:00 am	Drying and bleaching of exposed skeletal material Attempted animal scavenging of front legs and feet but could not detach due to the presence of tissue and ligaments Beetles and centipedes present
42 – Skeletonization August 29, 2008 – 12:00 pm	Drying and bleaching of exposed skeletal Material Most flesh left compared to other specimens Beetles present
56 – Skeletonization September 12, 2008 – 5:00 pm	Drying and bleaching of exposed skeletal material Second least decomposed compared to other specimens Beetles present
69 – Skeletonization September 25, 2008 – 3:00 pm	Drying and bleaching of exposed skeletal material Partially decomposed Flesh and hair still present All limbs and nose still intact Flesh appears moist

Table 11: Concrete surface results and observations of the decomposition process and insect activity of Pig 3

Day	**Observations**
1 – Fresh July 19, 2008 – 1:15 pm	No flies present Foaming at the mouth Livor mortis
2.1 – Early Decomposition July 20, 2008 – 8:30 am	Few flies present Foaming at the mouth Fire ants present on foam Greenish, blue, black and some purple discoloration of abdominal cavity Blistering of skin present near back right leg Liquid and gases leaking from natural and wound orifices Slight odor Beginning of bloating stage Livor mortis Rigor mortis
2.2 – Early Decomposition July 20, 2008 – 6:00 pm	Few flies present Least flies present Fire ants present Large spider near abdomen Exposure of large intestinal mass Livor and rigor mortis present Slight marbling present Blistering of skin present
3 – Early Decomposition July 21, 2008 – 11:00 am	Few flies present Most present in mouth No maggots activity Liquid and gases releasing from natural and wound orifices Intestinal mass continuing to enlarge Blistering of the skin Extensive marbling

Table 11-Continued: Concrete surface results and observations of the decomposition process and insect activity of Pig 3

4.1 – Early Decomposition July 22, 2008 – 9:00 am 4.2 – Early Decomposition July 22, 2008 – 2:00 pm	Few flies present Mostly in mouth and around anal cavity No maggot activity Fire ants present Blistering of skin Extensive marbling Few flies present No maggot activity
5 – Early Decomposition July 23, 2008 – 2:00 pm	Multiple flies present Light to moderate maggot activity Maggots in mouth, maggot masses on neck and abdominal cavity Least amount of maggots compared to other specimens Depressing abdominal cavity
6 – Early Decomposition July 24, 2008 – 11:30 am	Multiple flies present Extensive maggot activity Sagging of flesh Caving of abdominal cavity
7 – Advanced Decomposition July 25, 2008 – 1:00 pm	Multiple flies present Extensive maggot activity No beetles Sagging of flesh Partial exposure of the right humerus and ulna Slowest decomposition thus far
8 – Advanced Decomposition July 26, 2008 – 10:00 am	Few flies present Extensive maggot activity Maggots on and around body cavity No beetles
9 – Advanced Decomposition July 27, 2008 – 7:30 pm	Few flies present Extensive maggot activity Onset of mummification of outer tissues
10 – Skeletonization July 28, 2008 – 5:00 pm	Few maggots present Mummification
11 – Skeletonization July 29, 2008 – 6:30 pm	Mummification No beetles present
12 – Skeletonization July 30, 2008 – 7:30 pm	Mummification Bones retaining some grease No beetles present

Table 11-Continued: Concrete surface results and observations of the decomposition process and insect activity of Pig 3

14 – Skeletonization August 1, 2008 – 5:00 pm	Mummification Bones retaining some grease No beetles present
17 – Skeletonization August 4, 2008 – 6:00 pm	Mummification Drying of remaining tissues and bones Beetles present
20 – Skeletonization August 7, 2008 – 7:30 pm	Mummification Drying of remaining tissues and bones Beetles present
23 – Skeletonization August 11, 2008 – 4:00 pm	Mummification Drying and hardening of remaining tissues Beetles and fire ants present Strong odor still present Least decomposed thus far
33 – Skeletonization August 21, 2008 – 11:00 am	Mummification Drying and hardening of remaining tissues Beetles and fire ants present Strong odor still present
42 – Skeletonization August 29, 2008 – 12:00 pm	Mummification Drying and hardening of remaining tissues Beetles present
56 – Skeletonization September 12, 2008 – 5:00 pm	Mummification Drying and hardening of remaining tissues Beetles present
69 – Skeletonization September 25, 2008 – 3:00 pm	Drying and hardening of remaining tissues Barely decomposed Only visible skeletal element is the posterior portion of the vertebral column Most flesh and hair present compared to other specimens All limbs still intact Specimen appears moist Slowest to decompose out of the five specimens

Table 12: Sand surface results and observations of the decomposition process and insect activity of Pig 4

Day	**Observations**
1 – Fresh July 19, 2008 – 1:15 pm	No flies present Foaming at the mouth
2.1 – Early Decomposition July 20, 2008 – 8:30 am	Few flies present Foaming at the mouth Fire ants present on foam Small black beetle burrowed in sand Greenish black discoloration of abdominal cavity Blistering of skin Slight odor Beginning of bloating stage Livor mortis Rigor mortis
2.2 – Early Decomposition July 20, 2008 – 6:00 pm	Multiple flies present Most fire ants present Abdomen not ruptured Blistering of skin present Livor and rigor mortis subsiding Marbling present in extremities
3 – Early Decomposition July 21, 2008 – 11:00 am	Multiple flies present Most present underneath body cavity No maggots present Fire ants present Abdomen not ruptured Liquid and gases releasing from natural and wound orifices Marbling present
4.1 – Early Decomposition July 22, 2008 – 9:00 am	Multiple flies present Maggot activity along body cavity between extremities No fire ants present Blistering present on neck
4.2 – Early Decomposition July 22, 2008 – 2:00 pm	Multiple flies present Extensive maggot activity Maggot mass between extremities Sagging of flesh

Table 12-Continued: Sand surface results and observations of the decomposition process and insect activity of Pig 4

5 – Early Decomposition July 23, 2008 – 2:00 pm	Multiple flies present Extensive maggot activity Maggot mass on head, neck, and back Maggot mass in mouth Partial exposure of left ribs Sagging of flesh Decompressing of abdominal cavity
6 – Advanced Decomposition July 24, 2008 – 11:30 am	Multiple flies present Extensive maggot activity Bodily fluids staining sand surface Maggots in fluid around body cavity Partial exposure of left ribs and scapula Sagging of flesh Caving of abdominal cavity
7 – Advanced Decomposition July 25, 2008 – 1:00 pm	Multiple flies present Extensive maggot activity Partial exposure of the cranium, mandible, left humerus, and ribs Scapula detached from body cavity
8 – Advanced Decomposition July 26, 2008 – 10:00 am	Few flies present Moderate maggot activity Beetles present Onset of mummification of outer tissues
9 – Advanced Decomposition July 27, 2008 – 7:30 pm	Few flies present Moderate maggot activity Fire ants present Beetles present Mummification of outer tissues Left arm detached from body cavity
10 – Advanced Decomposition July 28, 2008 – 5:00 pm	Mummification No insects present Bones retaining some grease
11 – Skeletonization July 29, 2008 – 6:30 pm	Mummification Bones retaining some grease Flies present Fire ants present Beetles present
12 – Skeletonization July 30, 2008 – 7:30 pm	Mummification Bones retaining some grease Flies present Fire ants present Beetles present

Table 12-Continued: Sand surface results and observations of the decomposition process and insect activity of Pig 4

14 – Skeletonization August 1, 2008 – 5:00 pm	Mummification Bones retaining some grease Flies present Fire ants present Beetles present
17 – Skeletonization August 4, 2008 – 6:00 pm	Mummification Drying and bleaching of exposed skeletal material Beetles present
20 – Skeletonization August 7, 2008 – 7:30 pm	Mummification Drying and bleaching of exposed skeletal material Beetles present
23 – Skeletonization August 11, 2008 – 4:00 pm	Drying and bleaching of exposed skeletal material Fire ants present Disarticulation of left ribs, scapula, and humerus Odor still present
33 – Skeletonization August 21, 2008 – 11:00 am	Drying and bleaching of exposed skeletal material Flies present Beetles and centipedes present
42 – Skeletonization August 29, 2008 – 12:00 pm	Drying and bleaching of exposed skeletal material Flies present Beetles present
56 – Skeletonization September 12, 2008 – 5:00 pm	Drying and bleaching of exposed skeletal material Beetles present
69 – Skeletonization September 25, 2008 – 3:00 pm	Drying and bleaching of exposed skeletal material Partially decomposed and skeletonized Flesh and hair still present All limbs although front left arm is detached Flesh appears moist Skeletal elements stained brownish black, similar to the color of the sand surface

Table 13: Gravel surface results and observations of the decomposition process and insect activity of Pig 5

Day	**Observations**
1 – Fresh July 19, 2008 – 1:15 pm	No flies present Foaming at the mouth
2.1 – Early Decomposition July 20, 2008 – 8:30 am 2.2 – Early Decomposition July 20, 2008 – 6:00 pm	Few flies present Foaming at the mouth Fire ants present on foam Greenish black discoloration of abdominal cavity No blistering of skin Slight odor Beginning of bloating stage Rectal purge Livor mortis Rigor mortis Multiple flies present Abdomen not ruptured No blistering of skin Livor and rigor mortis subsiding Onset of marbling present
3 – Early Decomposition July 21, 2008 – 11:00 am	Multiple flies present Most present underneath body cavity in shaded areas No maggots present No fire ants present Enlarged rectal purge Abdomen not ruptured Liquid and gases releasing from natural and wound orifices Marbling on the extremities is present
4.1 – Early Decomposition July 22, 2008 – 9:00 am 4.2 – Early Decomposition July 22, 2008 – 2:00 pm	Multiple flies present Maggot activity along body cavity between extremities Maggot mass on back and anal cavity Multiple flies present Moderate maggot activity Maggot mass in the nose and mouth Maggot on the head, back, anus, and in between extremities

Table 13-Continued: Gravel surface results and observations of the decomposition process and insect activity of Pig 5

5 – Early Decomposition July 23, 2008 – 2:00 pm	Multiple flies present Extensive maggot activity Maggot mass on anus Sagging of flesh Decompressing of abdominal cavity
6 – Advanced Decomposition July 24, 2008 – 11:30 am	Few flies present Extensive maggot activity Maggot mass under skin Bodily fluids staining gravel surface Partial exposure of left ribs Sagging of flesh Caving of abdominal cavity
7 – Advanced Decomposition July 25, 2008 – 1:00 pm	Few flies present Extensive maggot activity Maggot mass along vertebral column Partial exposure of the cranium, mandible, left ribs, scapula, and humerus
8 – Advanced Decomposition July 26, 2008 – 10:00 am	Few flies present Extensive maggot activity Beetles present Onset of mummification of outer tissues
9 – Advanced Decomposition July 27, 2008 – 7:30 pm	Few flies present Slight maggot activity Fire ants present Beetles present Mummification of outer tissues
10 – Advanced Decomposition July 28, 2008 – 5:00 pm	Mummification No insects present Bones retaining some grease
11 – Skeletonization July 29, 2008 – 6:30 pm	Mummification Bones retaining some grease Flies present Fire ants present Beetles present
12 – Skeletonization July 30, 2008 – 7:30 pm	Mummification Bones retaining some grease Flies present Fire ants present Beetles present

Table 13-Continued: Gravel surface results and observations of the decomposition process and insect activity of Pig 5

14 – Skeletonization August 1, 2008 – 5:00 pm	Mummification Bones retaining some grease Flies present Fire ants present Beetles present
17 – Skeletonization August 4, 2008 – 6:00 pm	Mummification Drying and bleaching of exposed skeletal material Beetles present
20 – Skeletonization August 7, 2008 – 7:30 pm	Mummification Drying and bleaching of exposed skeletal material Beetles present
23 – Skeletonization August 11, 2008 – 4:00 pm	Drying and bleaching of exposed skeletal material Flies present Odor still present
33 – Skeletonization August 21, 2008 – 11:00 am	Drying and bleaching of exposed skeletal material Flies present Fire ants present Beetles and centipedes present Animal scavenged front left leg
42 – Skeletonization August 29, 2008 – 12:00 pm	Drying and bleaching of exposed skeletal material Flies present Fire ants present Beetles and centipedes present Animal scavenged front left leg
56 – Skeletonization September 12, 2008 – 5:00 pm	Drying and bleaching of exposed skeletal material Flies present Fire ants present Beetles and centipedes present Animal scavenged front left leg
69 – Skeletonization September 25, 2008 – 3:00 pm	Drying and bleaching of exposed skeletal material Partially decomposed and skeletonized Flesh and hair still present All limbs although front left arm is detached Thoracic vertebrae were gnawed by scavengers Flesh appears moist Skeletal elements stained blackish grey, similar to the color of the gravel surface

APPENDIX B

Figure 3: Pig 1: Control Surface – Stages of Decomposition

Day 2 – 7/20/08: Fresh Stage

Day 4 – 7/22/08: Early Stage

Day 7 – 7/25/08: Advanced Stage

Day 14 – 8/01/08: Skeletonization Stage

Day 69 – 9/25/08: Extreme Stage

Figure 4: Pig 2: Tarpaulin Surface – Stages of Decomposition

Day 2 – 7/20/08: Fresh Stage

Day 9 – 7/27/08: Advanced Stage

Day 4 – 7/22/08: Early Stage

Day 69 – 9/25/08: Skeletonization Stage

Figure 5: Pig 3: Concrete Surface – Stages of Decomposition.

Day 6 – 7/24/08: Early Stage

Day 2 – 7/20/08: Fresh Stage

Day 9 – 7/27/08: Advanced Stage

Day 69 – 9/25/08: Skeletonization Stage

Figure 6: Pig 4: Sand Surface – Stages of Decomposition.

Day 2 – 7/20/08: Fresh Stage

Day 5 – 7/23/08: Early Stage

Day 10 – 7/28/08: Advanced Stage

Day 69 – 9/25/08: Skeletonization Stage

Figure 7: Pig 5: Gravel Surface –Stages of Decomposition.

Day 2 – 7/20/08: Fresh Stage

Day 5 – 7/23/08: Early Stage

Day 10 – 7/28/08: Advanced Stage

Day 69 – 9/25/08: Skeletonization Stage

APPENDIX C

Day/Month	Day	Temp (ºC)			Humidity (%)			Precip	ADD	Wind†	Events
		high	avg	low	high	avg	low	ml		avg	
19-Jul	**1**	36.80	*28.26*	19.71	90.10	*56.41*	22.71	0.00	28.26	2.01	
20-Jul	**2**	37.27	*29.43*	21.58	86.40	*54.74*	23.08	0.00	57.69	1.90	
21-Jul	**3**	38.80	*30.41*	22.02	82.90	*49.44*	15.97	0.00	88.10	1.60	
22-Jul	**4**	37.71	*27.47*	17.22	81.80	*53.57*	25.33	0.00	115.57	1.55	
23-Jul	**5**	34.98	*28.46*	21.94	90.40	*62.45*	34.50	0.62	144.03	2.06	Rain
24-Jul	**6**	26.99	*24.97*	22.95	91.90	*83.35*	74.80	52.28	169.00	1.79	Rain
25-Jul	**7**	34.76	*29.05*	23.34	91.70	*63.61*	35.51	0.00	198.05	2.51	
26-Jul	**8**	35.98	*29.14*	22.30	90.90	*58.31*	25.71	0.00	227.19	1.72	
Week 1		***35.41***	***28.40***	***21.38***	***88.26***	***60.24***	***32.20***	***52.90***	***124.90***	***1.89***	
27-Jul	**9**	36.75	*28.98*	21.20	90.30	*56.49*	22.67	0.00	256.17	1.87	
28-Jul	**10**	36.97	*29.97*	22.97	87.20	*56.64*	26.08	0.00	286.14	2.23	
29-Jul	**11**	36.14	*29.34*	22.54	88.00	*58.98*	29.95	0.00	315.48	2.63	
30-Jul	**12**	35.15	*29.11*	23.06	86.80	*61.21*	35.61	0.00	344.59	2.17	
31-Jul	**13**	36.66	*30.65*	24.63	82.90	*57.46*	32.02	0.00	375.24	2.36	
1-Aug	**14**	35.99	*29.64*	23.30	88.60	*60.30*	32.00	0.00	404.88	1.90	
2-Aug	**15**	37.13	*30.28*	23.42	88.60	*58.50*	28.39	0.00	435.16	1.75	
Week 2		***36.40***	***29.71***	***23.02***	***87.49***	***58.51***	***29.53***	***0.00***	***278.60***	***2.13***	
3-Aug	**16**	38.09	*30.13*	22.17	88.00	*55.92*	23.83	0.00	465.29	1.55	
4-Aug	**17**	38.36	*29.07*	19.78	86.80	*55.69*	24.58	0.00	494.36	1.13	
5-Aug	**18**	36.59	*28.41*	20.23	87.10	*56.88*	26.66	1.87	522.77	0.88	Rain
6-Aug	**19**	36.22	*29.46*	22.69	89.10	*59.41*	29.72	0.62	552.23	2.11	Rain
7-Aug	**20**	37.02	*29.90*	22.78	87.40	*56.27*	25.14	0.00	582.13	1.88	
8-Aug	**21**	37.74	*29.56*	21.38	88.90	*56.93*	24.96	0.00	611.69	1.68	
9-Aug	**22**	37.81	*29.18*	20.55	89.80	*56.75*	23.70	0.00	640.87	2.03	
Week 3		***37.40***	***29.39***	***21.37***	***88.16***	***56.84***	***25.51***	***2.49***	***413.22***	***1.61***	
10-Aug	**23**	37.99	*30.89*	23.78	84.40	*55.28*	26.15	0.00	671.76	2.86	
11-Aug	**24**	36.93	*30.56*	24.18	82.40	*56.38*	30.35	0.00	702.32	2.28	
12-Aug	**25**	32.51	*27.68*	22.85	90.60	*69.27*	47.93	28.01	730.00	1.20	Rain
13-Aug	**26**	36.97	*29.16*	21.35	91.90	*58.12*	24.34	0.00	759.16	1.25	
14-Aug	**27**	37.05	*28.59*	20.13	91.30	*58.07*	24.84	0.00	787.75	1.35	
15-Aug	**28**	36.60	*29.32*	22.03	91.20	*61.78*	32.36	0.00	817.07	1.17	
16-Aug	**29**	35.20	*28.22*	21.24	91.50	*63.10*	34.69	19.29	845.29	1.26	Rain
Week 4		***36.18***	***29.20***	***22.22***	***89.04***	***60.29***	***31.52***	***47.30***	***566.13***	***1.62***	
17-Aug	**30**	31.36	*26.30*	21.23	91.70	*70.45*	49.19	18.36	871.59	1.09	Rain
18-Aug	**31**	25.54	*23.07*	20.59	92.20	*84.35*	76.50	18.05	894.66	0.77	Rain
19-Aug	**32**	29.55	*25.16*	20.76	91.90	*75.87*	59.83	6.22	919.82	1.02	Rain
20-Aug	**33**	34.69	*27.60*	20.51	92.00	*62.13*	32.26	0.00	947.42	0.88	

21-Aug	**34**	34.03	*27.34*	20.65	91.40	*67.76*	44.11	0.00	974.76	1.6	
22-Aug	**35**	33.64	*27.32*	21.00	91.10	*67.83*	44.55	3.11	1002.08	1.58	Rain
23-Aug	**36**	31.93	*26.23*	20.52	92.10	*69.47*	46.84	0.00	1028.31	0.94	
Week 5		***31.53***	***26.15***	***20.75***	***91.77***	***71.12***	***50.47***	***45.74***	***725.57***	***1.13***	
24-Aug	**37**	34.21	*26.99*	19.76	91.20	*65.30*	39.40	15.87	1055.30	1.06	Rain
25-Aug	**38**	36.62	*27.90*	19.18	91.70	*63.29*	34.88	17.43	1083.20	0.82	Rain
26-Aug	**39**	34.29	*26.41*	18.53	92.50	*67.74*	42.97	0.00	1109.61	0.76	
27-Aug	**40**	33.48	*26.37*	19.26	92.00	*67.32*	42.63	0.00	1135.98	1.02	
28-Aug	**41**	33.48	*26.94*	20.39	91.50	*67.37*	43.24	0.00	1162.92	1.08	
29-Aug	**42**	33.03	*26.90*	20.77	91.80	*68.25*	44.70	17.74	1189.82	0.79	Rain
30-Aug	**43**	33.32	*25.90*	18.48	92.80	*67.91*	43.01	0.00	1215.72	0.75	
Week 6		***34.06***	***26.77***	***19.48***	***91.93***	***66.74***	***41.55***	***51.04***	***901.60***	***0.90***	
31-Aug	**44**	34.46	*26.33*	18.20	92.20	*65.33*	38.45	0.00	1242.05	0.63	
1-Sep	**45**	34.52	*26.66*	18.80	91.60	*62.77*	33.94	0.00	1268.71	1.24	
2-Sep	**46**	37.86	*28.60*	19.34	87.50	*57.42*	27.34	0.00	1297.31	1.55	
3-Sep	**47**	34.54	*28.06*	21.58	81.80	*58.02*	34.23	0.00	1325.37	2.28	
4-Sep	**48**	33.53	*25.49*	17.45	89.50	*60.89*	32.28	0.00	1350.86	1.41	
5-Sep	**49**	33.72	*24.59*	15.46	91.40	*61.15*	30.90	0.00	1375.45	0.83	
6-Sep	**50**	33.62	*23.71*	13.79	92.20	*59.47*	26.74	0.00	1399.16	0.82	
Week 7		***34.61***	***26.21***	***17.80***	***89.46***	***60.72***	***31.98***	***0.00***	***1092.92***	***1.25***	
7-Sep	**51**	33.29	*22.78*	12.26	92.30	*61.26*	30.21	0.00	1421.94	1.07	
8-Sep	**52**	34.44	*26.46*	18.48	89.70	*61.98*	34.25	0.31	1448.40	1.80	Rain
9-Sep	**53**	33.67	*27.39*	21.10	90.10	*64.98*	39.85	0.00	1475.79	0.89	
10-Sep	**54**	34.00	*27.66*	21.32	89.30	*60.95*	32.59	0.00	1503.45	1.40	
11-Sep	**55**	35.28	*27.15*	19.02	90.90	*62.32*	33.73	0.00	1530.60	1.26	
12-Sep	**56**	34.90	*27.03*	19.15	89.60	*63.27*	36.93	0.00	1557.63	2.15	
13-Sep	**57**	38.35	*31.11*	23.87	87.80	*57.63*	27.45	0.62	1588.74	3.18	Rain
Week 8		***34.85***	***27.08***	***19.31***	***89.96***	***61.77***	***33.57***	***0.93***	***1290.05***	***1.68***	
14-Sep	**58**	33.46	*26.53*	19.59	91.30	*61.14*	30.97	0.00	1615.27	1.86	
15-Sep	**59**	25.44	*20.60*	15.76	68.84	*45.89*	22.93	0.00	1635.87	2.66	
16-Sep	**60**	29.27	*20.10*	10.92	80.30	*47.17*	14.03	0.00	1655.97	1.28	
17-Sep	**61**	27.72	*18.82*	9.91	82.30	*54.89*	27.48	0.00	1674.79	1.02	
18-Sep	**62**	28.62	*22.07*	15.52	89.90	*60.57*	31.23	0.31	1696.86	1.12	Rain
19-Sep	**63**	30.82	*20.66*	10.49	90.20	*59.15*	28.09	0.00	1717.52	0.99	
20-Sep	**64**	32.30	*21.34*	10.38	90.00	*58.32*	26.63	0.00	1738.86	1.04	
Week 9		***29.66***	***21.45***	***13.22***	***84.69***	***55.30***	***25.91***	***0.31***	***1490.33***	***1.42***	
21-Sep	**65**	33.06	*22.68*	12.29	90.10	*59.02*	27.94	0.00	1761.54	0.84	
22-Sep	**66**	33.93	*23.14*	12.34	89.80	*58.80*	27.80	0.00	1784.68	1.18	
23-Sep	**67**	32.97	*24.39*	15.80	90.00	*62.28*	34.56	0.00	1809.07	1.07	
24-Sep	**68**	32.08	*24.21*	16.33	89.50	*61.14*	32.78	0.00	1833.28	1.22	
25-Sep	**69**	31.27	*22.49*	13.70	90.80	*56.07*	21.33	0.00	1855.77	1.37	
Week 10		***32.66***	***23.38***	***14.09***	***90.04***	***59.46***	***28.88***	***0.00***	***1692.14***	***1.14***	
Weeks 1-10		**34.28**	**26.77**	**19.27**	**89.08**	**61.10**	**33.11**	**200.71**	**1692.14**	**1.48**	

LIST OF REFERENCES

Amendt J, Campobasso CP, Gaudry E, Reiter C, LeBlanc HN, Hall MJR
2007 Best practice in forensic entomology – standards and guidelines 121:90-104.

Amendt J, Zehner R, Krettek R
2004 Forensic entomology. Naturwissenschaften 91:51-65.

Anderson G and VanLaerhoven Sherah
1996 Initial Studies on Insect Succession on Carrion in Southwestern British Columbia. Journal of Forensic Sciences 41(4):617-625.

Bass WM
1997 Outdoor Decomposition Rates in Tennessee. In Forensic Taphonomy: The Postmortem Fate of Human Remains. William D. Haglund and Marcella H. Sorg, eds. Pp. 181-186. Boca Raton, FL: CRC Press LLC.

Bass WM and Meadows L
1990 Time Since Death and Decomposition of the Human Body: Variables and Observations in Case and Experimental Field Studies. Journal of Forensic Sciences 35:103-111.

Cahoon SE
1992 Effects of Clothing on Human Decomposition and Deterioration of Associated Yarns. M.A. thesis, The University of Tennessee, Knoxville, TN.

Campobasso C, Di Vella G, Introna F
2001 Factors Affecting Decomposition and Diptera colonization. Forensic Science International 120:18-27.

Carter DO, Yellowless D, Tibbett M
2007 Cadaver Decomposition in Terrestrial Ecosystems. Naturwissenschaften 94:12-24.

Catts EP
1990 Analyzing Entomological Data. In: Catts E, Haskell N, editors Entomology and death: A Procedural Guide. Clemson: Joyce's Print Shop, Inc., Pp. 124-135.

Catts EP
1991 Analyzing Entomological Data. Clemson, SC: Joyce's Print Shop. Pp. 24-35.

Catts EP
1992 Problems with Estimating the PMI in Death Investigations. Journal of Agricultural and Urban Entomology 9(4):245-255.

Catts EP and Goff ML
1992 Forensic Entomology in Criminal Investigations. Annual Review of Entomology 37:252-272.

Clark MA, Worrell MB, Pless JE
1997 Postmortem Changes in Soft Tissues. In:Haglund WD, Sorg MH, editors. Forensic Taphonomy: The Postmortal Fate of Human Remains. CRC Press, Boca Raton, FL. Pp. 151-170.

Cotton GE, Aufderheide AC, Goldschmidt VG
1987 Preservation of Human Tissue Immersed for Five Years in Fresh Water of Known Temperature. Journal of Forensic Sciences 32(4):1125-1130.

Davidson J
1944 On the Relationship Between Temperature and Rate of Development of Insects at Constant Temperatures. Journal of Animal Ecology 13:26-38.

Dent BB, Forbes SL, Stuart BH
2004 Review of Human Decomposition Process in Soil. Environmental Geology 45:576-585.

Fairbridge RW
1967 Climatic Classification. The Encyclopedia of Atmospheric Sciences and Astrogetology. Encyclopedia of Earth Science. Series 2:172-185.

Fiedler S and Graw M
2003 Decomposition of buried corpses, with special reference to the formation of adipocere. Naturwissenschaften 90:291-300.

Galloway A
1997 The Process of Decomposition: A Model from the Arizona-Sonoran Desert. In:Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, FL: CRC Press. Pp. 139-147.

Galloway A, Birkby WH, Jones AM, Henry TH, Parks BO
1989 Decay Rates of Human Remains in an Arid Environment. Journal of Forensic Sciences 34:607-616.

Goff ML
1993 Estimation of the Postmortem Interval Using Arthropod Development and Successional Patterns. Forensic Science Review 81:81-94.

Goff ML and Flynn MM
1991 Determination of Postmortem Interval by Arthropod Succession: A Case Study from the Hawaiian Islands. Journal of Forensic Sciences 36:607-614.

Greenberg KB
2002 Entomology and the law – flies as forensic indicators. Cambridge University Press, Cambridge, UK.

Haglund WD, Reichert DG, Reay DT
1990 Recovery of Decomposed and Skeletal Human Remains in the Green River Murder Investigation: Implications for Medical Examiner/Coroner and Police. American Journal of Forensic Medicine and Pathology 11:35-43.

Haglund WD and Reay DT
1993 Problems of Recovering Postmortem Artifacts of Bone and Soft Tissue. Journal of Forensic Sciences 38:69-80.

Hall RD
1991 Medicocriminal Entomology. Clemson, SC: Joyce's Print Shop. Pp. 1-8.
Haskell N, Hall R, Cervenka V, Clark M (1997) On the Body: Insects' Life Stage Presence and Their Postmortem Artifacts. In:Haglund W, Sorg M, editors. Forensic Taphonomy. Boca Raton: CRC Press. Pp. 415-448.

Heinsch FA, Heilman JL, McInnes KJ, Cobos DR, Zuberer DA, Roelke DL
2004 Carbon dioxide exchange in a high marsh on the Texas Gulf Coast: effects of freshwater availability. *Agricultural and Forest Meteorology* 125:1-2. 159-172.

Henβge C, Madea B, Knight B, Nokes L, Krompecher T
1995 The estimation of the time since death in the early postmortem interval. Arnold, London.

Hewadikaram, K and Goff ML
1991 Effects of Carcass Size on Rate of Decomposition and Arthropod Succession Patterns. American Journal of Forensic Medical Pathology 12(3):235-240.

Ibrahim YM and Dennis RE
1982 Growing Seasons of Arizona and Sonora. Journal of Agronomy and Education 11:29-32.

Kamal A
1958 Comparative Study of Thirteen Species of Sarcoasprophagous, Calliphoridae, and Scarcophagidae (Diptera). Annual Entomological Society of America 51:261-271.

Mann RW, Bass MA, Meadows L
1990 Time Since Death and Decomposition of the Human Body: Variables and Observations in Case and Experimental Field Studies. Journal Forensic Sciences 35:103-111.

Megyesi MS, Nawrocki SP, Haskell NH
2005 Using Accumulated Degree-Days to Estimate the Postmortem Interval from Decomposed Human Remains. Journal of Forensic Sciences 50(3):1-9.

Mellen PFM, Lowry MA, Micozzi MS
1993 Experimental Observations on Adipocere Formation. Journal of Forensic Sciences 38:91-93.

Micozzi MS
1986 Experimental Study of Postmortem Change Under Field Conditions: Effects of Freezing, Thawing, and Mechanical Injury. Journal of Forensic Sciences 32:953-961.

Micozzi MS
1991 Postmortem Change in Human and Animal Remains. Springfield, IL: Charles C. Thomas.

Payne JA
1965 A Summer Carrion Study of the Baby Pig *Sus scrosfa* Linnaeus. Ecology 46:592-602.

Reed HB
1958 A Study of Dog Carcass Communities in Tennessee, with Special Reference to the Insects. American Midland Naturalist 59:213-245.

Richardson EA, Seeley SD, Walker DR
1974 A Model for Estimating the Completion of Rest for 'Redhaven' and 'Elberta' Peach Trees. HortScience 9:331-332.

Ritchie, GT
2005 A Comparison of Human Decomposition in an Indoor and an Outdoor Environment. M.A. thesis, The University of Tennessee, Knoxville, TN.

Rodriguez WC and Bass WM
1983 Insect Activity and its Relationship to Decay Rate of Human Cadavers in East Tennessee. Journal of Forensic Sciences 28:423-432.

Shean B, Messinger L, Papworth M
1993 Observations of Differential Decomposition on Sun Exposed v. Shaded Pig Carrion in Coastal Washington State. Journal of Forensic Sciences 38(4):938-949.

Schoenly K, Griest K, Rhine S
1991 An Experimental Field Protocol for Investigating the Postmortem Interval Using Multidisciplinary Indicators. Journal of Forensic Sciences 36:1395-1415.

Skinner MF, Syed A, Farrell J, Borden JH
1988 Case Report in Forensic Anthropology: An Animal and Insect Factors in Decomposition of Homicide Victim. Canadian Society Forensic Science Journal 21:71-81.

Sledzik PS
1997 Forensic Taphonomy: Postmortem Decomposition and Decay. *In* Forensic Osteology: Advances in the Identification of Human Remains, 2nd edition. Kathleen J. Reichs, ed. Pp. 109-119. Springfield, IL: Charles C. Thomas.

Sumodan PK
2002 Insect Detectives: Forensic Entomology. Resonance 7(8)51-58.

Ubelaker DH
1989 Human Skeletal Remains. Excavation, Analysis, Interpretation. 2nd ed. Taraxacum, Washington, D.C.

Vass AA, Bass WM, Wolt J, Foss J, Ammons J
1992 Time Since Death Determinations of Human Cadavers Using Soil Solution. Journal of Forensic Sciences 37:1236-1253.

Vass AA, Smith RR, Thompson CV, Burnett MN, Dulgerian N, Eckenrode BA
2008 Odor Analysis of Decomposing Buried Human Remains. Journal of Forensic Sciences 53(2):384-391.

Zalom FG, Goodell PB, Wilson LT, Barnett WW, Bentley WJ
1983 Degree-Days: The Calculation and Use of Heat Units in Pest Management. The University of California and The United States Department of Agriculture.

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