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# The Effect of Various Coverings on the Rate of Human Decomposition

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To the Graduate Council:

I am submitting herewith a thesis written by Angela Madeleine Dautartas entitled "The Effect of Various Coverings on the Rate of Human Decomposition." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Lee Meadows Jantz, Major Professor

We have read this thesis and recommend its acceptance:

Richard Jantz, Murray Marks

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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# The Effect of Various Coverings on the Rate of Human Decomposition

A Thesis presented
for the Master of Arts Degree
The University of Tennessee, Knoxville

Angela M. Dautartas
August 2009

## Dedication

To Drs. Donna and Cliff Boyd, who first introduced me to Anthropology, and who continue to inspire my pursuit of knowledge in this field. Thank you both.

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I would like to thank many people, including my major professor, Dr. Lee Meadows Jantz for her instruction and encouragement, Dr. Richard Jantz for his statistical advice and Dr. Murray Marks for his guidance.

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## Abstract

A multitude of factors can affect the decomposition process, increasing or decreasing its rate. Some of the most frequently observed variables are temperature, moisture, insect activity, and sun or shade exposure.

Coverings can impact the decomposition process, and are found frequently in forensic cases. In a survey of New Mexico cases, Komar (2003) reported that sixteen individuals were found wrapped in plastic, and twenty were noted as wrapped in a cloth or blanket. In a survey conducted of eighty-seven cases, fifty-four of the bodies were wrapped in some type of covering. Plastic was most common, but a variety was noted, including rugs, sleeping bags, and blankets, (Manhein, 1997).

In order to document how coverings affect early decomposition an experiment was designed to mimic a forensic setting. Three human cadavers were used in each of two repetitions of this experiment. Two of the cadavers were covered, one in plastic tarp, the other in a cotton blanket, while the third was left uncovered as a control. The selection of materials was based on case reports of cadavers wrapped in plastic and blankets (Komar, 2003, Derrick, 2007 personal communication). Demographic and environmental variation between individuals was kept to a minimum.

Data collected included daily minimum and maximum temperatures and two daily temperature point comparisons. The bodies remained covered for thirty days during this data collection. At the end of that period, the bodies were uncovered and the amount of decomposition was recorded.

Using the temperature data, the accumulated degree days (ADD) were calculated and compared to the actual number of days postmortem. This technique provided a basis of comparison between the temperature data recorded and the expected decomposition rate. This also allowed for comparison between calculated ADD and estimated ADD following Megyesi et al., (2005).

Repeated measures analysis of variance did not show significant differences between temperatures collected from covered versus uncovered bodies. Variation between the calculated ADD, estimated ADD and the actual number of days postmortem was not significant, but still showed marked differences. This suggests that special consideration should be taken when estimating time since death in cases involving covered bodies.

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## I. Introduction

Taphonomic research has become increasingly common in forensic anthropology. Taphonomy is a field of study that examines all of the processes that alter biological organisms from the time of death (Haglund and Sorg, 1997, 2002). Environmental, biological, chemical and even cultural factors can affect how matter decomposes. Explaining precisely how these factors affect the speed of human decomposition can aid in determining post mortem interval (PMI), which is an important piece of information in forensic contexts. An accurate assessment of PMI can help narrow the missing persons data to be surveyed, and can also help establish a clear timeline for the case as a whole.

This research has two major purposes: First, to assess whether covering a body with various materials will significantly affect the rate of decomposition. This is a pertinent question because the rate of decomposition is crucial to estimating the post-mortem interval. Forensic anthropologists are frequently consulted to estimate time since death, and any information which allows for more accurate estimations is beneficial. The question of statistical significance is relevant because while differences in decomposition may occur, if they are not extreme then those differences can be treated as negligible. If they do affect the estimation, then they should be accounted for in order to create the most accurate estimation possible.

The reasoning behind developing research to empirically test whether coverings will affect decomposition comes from use of PMI estimates in legal cases, and the need for forensic anthropologists to testify to their findings in court. According to the standards set down by *Daubert v. Merrell-Dow Pharmaceuticals, Inc.* in order for scientific testimony to be admitted, the techniques referred to must first be tested using the scientific method (Christensen, 2004).

While this is only one of several key standards set down by the court ruling, it is a necessary first step. Increasing the number of factors affecting decomposition that have been empirically tested aids in moving towards a wider base of techniques applicable for use in medico-legal cases.

The null hypothesis is that there will be no difference in the rate of decomposition between the bodies subjected to different postmortem treatments. The alternate hypothesis is that there will be differences in the rate of decomposition between the different control and experimental groups. In order for the null hypothesis to be accepted, no significant differences should be found between the temperatures measured from each body. The visual indictors of decomposition would be expected to be similar between all experimental units for the null hypothesis to be supported. If significant differences are found between the temperature measurements, then the alternate hypothesis should be accepted.

The second major goal of this project was designed following the work of Megyesi et al. (2005). Their research attempted to develop a system for accurately estimating accumulated degree days based on body decomposition as a way to then estimate the post-mortem interval. In their study a total of 68 bodies were examined but only two of these were in coverings. The covered bodies were found to be outliers, but not significantly removed from the rest of the sample. The second goal of my research then became to test whether or not the method developed by Megyesi and colleagues would work well when applied specifically to covered bodies, or if using a different method of determining accumulated degree days would be more appropriate in this situation. Finding the best method of estimation would again affect the eventual estimation of time since death, and is therefore useful for adding to the forensic knowledge base.

## Stages of Soft Tissue Decomposition

Decomposition follows several predictable, sequential stages. Researchers have attempted to define each stage and its approximate length, but the duration is often affected by a myriad of conditions: However, an approximation of time since death can still be estimated by observing the condition of the body and noting the state of decay (DiMaio and DiMaio, 2001). The specific stages of decomposition represent a continuum and their duration here was created primarily for scientific convenience. As such, they are not always agreed upon. Present research is underway to attempt to more clearly define each stage and the processes belonging to each. In addition, scientists continually undergo research to better understand the variables that can affect each stage, and unique case-based examples are often documented to illustrate possible variations within the process. During the early or "fresh" stage of soft tissue decomposition, three processes take place, which adhere to a relatively strict timeline. These processes are rigor mortis, livor mortis, and algor mortis. A body is considered "fresh" during the first twenty-four to forty-eight hours after death (Galloway et al., 1989). After this time, a body moves into the "decomposed" stage, marked by signs such as distinct color changes and skin slippage (Galloway et al.1989). The third and final stage, the "dry" stage, manifests itself through significant tissue loss and subsequent bone exposure (Galloway et al., 1989).

## The "Fresh" Stage

### *Rigor mortis*

Rigor mortis refers to the process of muscle stiffening which results from a buildup of lactic acid in the tissues following death (Janaway, 1996). The muscles will begin to seize up,

and eventually all of the muscle tissue in the body will become fixed and immobile (Spitz and Fischer, 1980). This process begins within 2 to 4 hours after death, peaks at twelve hours post mortem, begins to recede at twenty-four hours, and is completely dissipated by thirty-six hours post-mortem (Janaway, 1996). This process takes time to complete because cell death and the buildup of waste products do not happen instantaneously. Once the process has completely subsided, the body will be limp and flexible. This process is quite useful for medical examiners in determining time since death, because the variation in duration is relatively slight, and is also quite easy to recognize.

*Livor mortis*

The second process that is sometimes used to determine post mortem interval is livor mortis (Kaatsch et al., 1994). When the cells break down and circulatory activity ceases, blood responds to gravity and settles in the lowest points of the body, creating visible red areas on the skin (Baden and Hennessee, 1989). This process, although affected by other variables, generally begins within an hour post mortem and takes around eight hours to complete (Baden and Hennessee, 1989). In addition, if a body is moved after this time period, lividity will be fixed and "stains" will be visible at the original site of contact. The pools of blood will not travel due to movement of the body, and therefore can be useful in determining not only post mortem interval but primary or secondary placement as well (Perper, 1993).

*Algor mortis*

The third process, algor mortis, refers to the lowering of the body temperature post mortem. Typically, temperature drops two degrees within the first twelve hours after death, and

then continues to decrease at a rate of about one degree per hour (Perper, 1993). Simple calculations are then needed to determine the time since death. However, this temperature can be affected by ambient temperature and bacterial activity.

Each of these processes can be used to estimate a time since death that is generally accurate within a few hours; however, these techniques will cease to be effective at thirty-six hours post mortem, creating a need to develop a timeline for the processes later in the decomposition sequence.

## The "Decomposed" Stage

### *Autolysis*

Subsequently in the decomposition process, when the body is no longer considered "fresh", autolysis occurs. Autolysis is the name given to the massive cell death that results in a complete loss of cellular integrity and widespread necrosis (Love and Marks, 2003). The cessation of circulatory activity and the subsequent loss of adenosine triphosphate (ATP) cause swelling of the cell wall and a mixing of the extracellular matrix and the surrounding cell tissue (Spitz and Fischer, 1980). This process then leads to a drop in the pH of the cytoplasm. Enzymes within the cytoplasm then become active and further deteriorate the cellular material. Externally, massive color change is evident in the skin, which becomes paler, and skin slippage is often observable (Love and Marks, 2003). A green discoloration due to bacterial activity is also often observable in the abdominal region.

### *Putrefaction*

Autolysis then encourages the onset of putrefaction, which generally commences forty-eight to seventy-two hours after death (Janaway, 1996). During this stage of decomposition,

internal bacteria begin to break down the surrounding tissue (Coe, 1993). As the oxygen within the body decreases, this creates a more suitable anaerobic environment for the destructive bacteria responsible for putrefaction activity (Macchiarelli and Feola, 1995). Most of the bacteria inside the body are concentrated within the cecum, and therefore most of the external signs of putrefaction are first visible in the abdominal area (Love and Marks, 2003).

By-products of this activity include large-scale production of hydrogen and other gases, which cause observable bloating of the abdominal cavity (Gill-King, 1997). In addition, the discoloration that begins in the abdomen spreads to other areas of the body as the bacteria travel throughout the tissue. Discoloration is often inconsistent and produces a "marbling" effect (Love and Marks, 2003). This specific stage of the decomposition process is one of the most significantly affected by environmental conditions (Janaway, 1996). Moisture, temperature, and other bacteria can all affect the duration of this process (Janaway, 1996).

Once most of the gases have been expulsed and the tissue continues to break down, bloating ceases. Prior to the complete cessation of bloating, initial skeletalization begins (Love and Marks, 2003). This process typically begins in the face. Once the bloating has completely subsided, the soft tissue remaining on the body continues to deteriorate (Love and Marks, 2003). At this point, most of the head hair and body hair has loosened and come away from the body, and extensive skin slippage has occurred (Galloway et al., 1989). This process is also quite variable in its duration, depending upon environmental and internal conditions.

*Decay*

The decay stage consists primarily of increased and intensive internal decomposition. Skin cracks and eventually disintegrates along with other soft tissues (Galloway et al., 1989).

The internal tissue becomes increasingly exposed to the environment, which allows for oxygen to enter in. This then increases the aerobic bacterial activity, which accelerates tissue decomposition (Rodriguez and Bass, 1983). Any remaining head hair sloughs off from the body and forms a "hair mat," a mass of matted hair which collects beneath the head. Bodily fluids leak out of the body, which allows for the exposure of bone, and the remains begin drying out. Once this process begins, more bone is exposed, leading to the dry stage.

## The "Dry" Stage

*Skeletonization*

The final stage of the decomposition process involves little or no soft tissue remaining, with extensive skeletalization evident over the entire body (Rodriguez and Bass, 1983). Although there can be a great deal of variation in the preservation of skeletal material, any state after skeletalization is considered to be part of a single stage of the decomposition process. This stage can persist for months or years, and is punctuated only by the eventual breakdown of the bones themselves. Once a body has reached this stage, determination of time since death can be quite difficult, because bone preservation will depend more on the environmental circumstances than natural decay. Animal scavenging, weather conditions, soil acidity, and other factors can all affect how well bone material remains intact.

## Factors affecting the rates of decomposition

A multitude of factors can affect each stage of the decomposition process, either accelerating the process or slowing it down, depending on the specific agent at work. Some of the most frequently observed variables are temperature, moisture, insect activity, and sun or

shade exposure. Whether the remains are left on the surface or have been buried or submerged also has a significant impact. Typically, several or all of these influences affect the decomposition process, and the effects are seen in multiple stages. The fact that these influences interact throughout the entire process is what makes the sequence so variable.

*Temperature*

Temperature always affects the rate of decomposition. The general trend observed is that warmer conditions will promote decay, and colder climates will delay the process (Smith, 1984). Warmer environments are more favorable for bacterial activity, which aids in decomposition. Surrounding plant matter can also have an effect on decomposition by influencing temperature. Mant (1987) found in his examination of World War II burials that straw and pine needles covering decomposing matter retained heat produced by the decomposition process and generated heat through their own breakdown. This increase in temperature accelerated the rate of decomposition; however, extremely high temperatures can prohibit bacterial growth and replication (Micozzi, 1997). On the other end of the spectrum, freezing can significantly prolong the decomposition process. Putrefaction can even be completely halted at extremely cold temperatures (Micozzi, 1991). The cold temperature acts as a preservation agent for the tissue, and the climate often also discourages both insect and scavenger activity (Janaway, 1996).

*Moisture*

The amount of moisture surrounding the body also factors into the duration of decomposition. Typically, a moister environment fosters decomposition, and more arid climates retard the process (Smith, 1984). Well-drained, dry soil has also been shown to be conducive to

mummification (Mant, 1987). The combination of heat and aridity can be particularly likely to lead to mummification of remains. This combination is a strong example of how factors often interact to affect the rate of decomposition. Very rarely does a single factor determine how quickly or slowly a body decomposes. Aturaliya and Lukasewyz (1999) examined the importance of moisture content to the rate of decomposition by using rat carcasses in a taphonomic study. Their research noted that the material or environment that was in direct contact with the skin of the decomposing body made the most significant impact in moisture loss or retention (Aturaliya and Lukasewyz, 1999). Materials that absorbed moisture and then allowed for evaporation accelerated water loss and led to faster desiccation of tissue or mummification. Materials that allowed water to collect on the carcass prevented mummification, regardless of whether the body was buried or placed on the surface (Aturaliya and Lukasewyz, 1999).

*Individual variation*

Decomposition can also be affected by physical conditions of the individual (Stuart, 2003). Thinner bodies tend to skeletonize more rapidly than individuals with higher body fat (Mant, 1987). This is partially due to the fact that an excessive amount of body fat can hinder dissipation of heat, and heat is an essential component of rapid decomposition (Gonzales et al., 1954). In addition, body fat provides an ample amount of liquid needed for bacterial growth, which is active during several stages of decomposition. Thus, although bodies with a higher fat content will begin to decompose quickly, the overall process leading to skeletonization will require more time. An ante mortem infection can also contribute to accelerated putrefaction, as microbial agents are already active within the body prior to the start of decomposition (Polson,

1996). Wounds on the body also speed up decomposition, primarily due to their influence on attracting insect activity. Insects typically approach natural orifices; however, wounds provide additional places for feeding and egg deposition (Mann et al., 1990).

*Oxygen content*

Another key factor in decomposition speed is the access or restriction of oxygen content on the body (Mant, 1987). Oxygen is needed for aerobic bacterial activity, which is a significant part of putrefaction. Mant (1987) observed a mass grave in which a small section of the burial had been opened over the lower chest and abdomen of one individual. Decomposition was advanced, showing a loss of all thoracic organs and associated soft tissue. The other individuals within the grave who had not been exposed to the air retained a lesser state of decomposition.

**Insects**

Insect activity is arguably one of the most important factors affecting decomposition. Insects accelerate the decomposition process (Gonzales et al., 1954). Ants, blowflies, beetles, and cockroaches all affect decomposing tissue. Blowflies are typically the first insects attracted to the body; they can be observed on a corpse minutes after deposition (Campobasso et al., 2001). These insects lay eggs around the orifices of the mouth, nostrils, eyes and genitals, and any open wounds. These eggs then hatch into maggots within eight to fourteen hours (Campobasso et al., 2001),

*Maggot activity*

The maggots disrupt soft tissue, burrowing into the flesh. The larvae also decompose proteins in the soft tissue, which leads to liquefaction of the area (Evans, 1963). Large numbers

of maggots are generally produced, and the collective group is often able to damage much of the soft tissue within a short period of time. Maggots also help to disseminate bacteria throughout the body as they travel while feeding (Lord, 1990). Activity of the maggot mass also produces a great deal of heat, which further stimulates decomposition (Mann et al., 1990). Insect activity rates are variable depending upon ambient temperature, and on sun or shade exposure. Direct sunlight leads to more rapid insect succession but smaller populations, while shady areas typically exhibit larger insect populations, but slower onset (Srnka, 2003).

*Seasonality*

Fly species are also constrained by season (Greenberg and Kunich, 2002). Certain blowflies will only appear during the summer months, while others favor cold weather. This information can also be of importance in determining both time since death and possible movement of the body. The usefulness of seasonality data can be complicated by the fact that bodies can be moved indoors, with artificial temperature settings that can harbor normally out of season insects. Atypical weather, such as heat waves or cold spells, can also confound the seasonality data. Sometimes a shift in temperature leads normally diurnal flies to become more active at night, or to less frequent breeding (Greenberg and Kunich, 2002).

*Secondary burial*

The presence or absence of certain species of insects can also indicate if a body was initially placed on the surface then buried (Haskell et al., 1997). If a body was interred several days after death, there would typically be a large number of flies on the body in varying life stages, but there would be a notable absence of any of the species that normally colonize a body

in the later stages of decomposition (Haskell et al., 1997). In addition, deep burial of a body can sometimes prevent flies from being able to access a corpse (Greenberg and Kunich, 2002). A body removed from a deep burial that shows evidence of insect activity suggests that the remains were exposed to surface conditions for a time prior to burial.

**Animal activity**

Non-insect scavengers can also affect decomposition rates. Both mammalian carnivores and rodents can partake in dismemberment and disarticulation of a body during decomposition. Large carnivores such as wolves or dogs are usually primarily responsible for disarticulating limbs from the torso and for eating away at the face, neck, and abdominal areas (Willey and Snyder, 1989). Rodents typically gnaw at the long bones as opposed to eating the soft tissue (Haglund et al., 1989, Klippel and Synstelien, 2007). Both the carnivores and rodents also are known for scattering remains.

**Surface vs. Buried**

Whether remains are deposited on the surface or buried also greatly affects decomposition. Burial of remains inhibits both insect and mammalian scavenging activities, and therefore can delay decomposition. Also, temperatures above ground are generally higher than below the surface (Janaway, 1996). In addition, burial generally protects the remains from weathering activities which damage the tissue. The depth of burial also factors into decay rates. As a general trend, a deeper interment will provide better preservation of remains, due to more stable temperatures and better protection from surface factors (Mant, 1987).

Burial of bodies can also make detection of bodies more difficult, which results in bodies being interred for a longer period of time and thus further decomposing prior to being recovered and analyzed. In an attempt to deal with this issue, Vass et al. (2004) have begun research on the chemicals released during decomposition and the odors which they emit. By building a database of decompositional odors, the researchers hope to develop a chemical sensor that can detect buried bodies without the aid of cadaver dogs. In order to collect the necessary data, Vass and colleagues conducted research over a year and a half period, and collected chemical samples from bodies buried in shallow graves (Vass et al., 2004).

## Synthetic factors influencing decomposition rates

Forensic anthropologists and other scientists often attempt to study decomposition rates and patterns by compiling information gathered from individual forensic cases. These case studies can then be compared with other similar situations, and commonalities and differences can be discovered. Anecdotal information also provides a useful starting point for developing future research topics. Common trends seen in the forensic cases can provide questions that fuel hypotheses and experimental designs.

### *Clothing*

The idea to study how clothing affects the decay rate probably stemmed from case reports. In a review of forensic anthropology casework in New Mexico, 120 of 598 cases were reported to include clothed individuals found at the crime scene (Komar, 2003). Although this seems to be a small percentage of the total number of cases, instances where the individual was clothed were frequent enough that further study of the effects of clothing would prove useful.

Also, not all of the individuals were clothed in the same manner. Seventy-four individuals were found in light summer clothing, while forty-six individuals were dressed in winter clothing (Komar, 2003).

Clothing also promotes adipocere formation (Miller, 2002). Adipocere can be defined as an insoluble soap formed from fatty acids which hydrolyze with bivalent ions (Jackowski et al., 2005). However, the presence of clothing on a surface deposition has been shown both to slow and to accelerate decomposition, depending upon other factors (Cahoon, 1992, Miller, 2002). Other types of covering such as plastic bags, carpets and tarps can also affect the decomposition rates of buried bodies in a similar fashion. For example, plastic bags have been observed to increase adipocere formation by trapping moisture (Miller, 2002).

*Other coverings*

Clothing, although possibly the most frequently studied covering, is not the only type of covering to be reported on a deceased individual. In the same survey of New Mexico cases, Komar (2003) reported that sixteen individuals were found wrapped in plastic, and twenty were noted as wrapped in a cloth or blanket. A canvas tarp was found wrapped around another individual, and two instances were reported in which individuals were located in burlap bags (Komar, 2003).

Variation in body coverings spans a wide spectrum. A case from Singapore involved the remains of a child found wrapped in nine layers of plastic and then placed in a plastic bag (Chui, 2006). In this instance, the body was reportedly in a state of much higher preservation than expected for the hot, humid climate (Chui, 2006). Again, this illustrates how coverings can dramatically affect estimation of post mortem interval. Individuals are sometimes responsible for

their own placement in odd coverings. One suicide report detailed how an individual wrapped himself in a large plastic bag and then connected plastic tubes between the bag and two gas tanks (Piatigorsky, 2006).

Manhein (1997) discusses several case studies from Louisiana that she had examined. In one of these cases, a body had been deposited in a plastic bag, which appeared to preserve the body. A second case study had a woman wrapped in a polyester mattress cover, which did not seem to preserve the remains. Still a third case introduced another type of fabric; a man was wrapped in a vinyl tablecloth prior to disposal (Manhein, 1997). In a survey conducted of eighty-seven cases, fifty-four of the bodies were wrapped in some type of fabric prior to burial. Plastic was one of the most common fabrics, but a wide variety was noted, including rugs, sleeping bags, blankets, and clothing (Manhein, 1997). Another instance of unusual deposition happened in Virginia. A man murdered his wife and buried her charred remains wrapped in a carpet (Glassman, 2003).

*Burials and coverings*

Both surface deposits and burials have been noted to include some type of covering over the body. Coverings on buried bodies produce a variety of effects. A body buried directly in the soil, for example, will decompose differently than a body buried within a coffin (Dent et al., 2004). Mant (1987) found that coffins that warped quickly after burial provided an air pocket around the body. When compared to bodies buried directly in soil, the coffin bodies showed accelerated rates of decomposition. Clothing on a buried body typically slows decomposition (Mant, 1987). Coverings that provide a more air-tight environment, such as a 55-gallon steel drum, can lead to complete mummification of a body (Catanese and Bloom, 2002).

Mummification can be defined as a drying out of tissues which results in preservation of the body (Catanese and Bloom, 2002).

**Estimating the post-mortem interval**

The purpose behind studying how various factors influence the rate of decomposition is to better predict post mortem interval (PMI). Scientists attempt to take the information garnered from anecdotal cases and actualistic studies and develop formulae or discrete patterns that can be applied in a wide variety of case situations. For example, Vass et al. (2002) studied the chemical composition of decomposing remains in order to develop usable biomarkers for determining PMI. In order to develop a usable timeline, bodies were allowed to decompose at a research facility over a time period of four years, and tissue samples were collected to be analyzed for specific biomarkers such as amino acids and neurotransmitters (Vass et al., 2002). This chemical signature was then matched to time since death. Ideally, this information could then be applied to future cases, and PMI can be estimated based on the chemical composition of a tissue sample taken from a recovered body.

**Entomology and Post-Mortem Interval Estimation**

Several species of insects, including flies, beetles and moths, have been used as estimators of post-mortem interval since approximately 1894 (Greenberg and Kunich, 2002). Much research into forensic entomology has been conducted in recent years to better define the use of insect activity as a proxy for time since death, but the basic concepts of the science are centuries old. Early criminal investigators and medical professionals noted that certain species of insects could reliably be found with any deceased individual, and that the life cycle of those

insects followed a predictable timeline (Greenberg and Kunich, 2002). Correctly identifying the insects present at a death scene and determining their stage in the life cycle could produce an accurate estimate of time since death.

**Factors influencing time since death estimations**

One important clue to time since death determinations is the amount of body mass of a corpse that can be lost to the larvae of blowflies during the first few days of decomposition. As much as sixty percent of the body mass can be consumed by maggots in a relatively brief time period (Greenberg and Kunich, 2002). This rapid loss of soft tissue could cause investigators to estimate a much longer time since death interval than is accurate if they are unaware of common blowfly behavior. Other insects that traumatize remains during this phase of decomposition include cockroaches, lice, ants, bees, and wasps (Haskell et al., 1997). Knowledge of the typical behavior of these species allows investigators to more accurately determine the post-mortem interval.

**Accumulated Degree Days (ADD)**

Researchers have a multitude of ways to describe time since death. Older literature referred to this time period in number of days since death, or total hours since death. Recently, accumulated degree days (ADD) have become increasingly more prevalent as a standardized unit of measure for post-mortem interval. Accumulated degree days first appeared in the literature in an article by Edwards et al. (1987), which was featured in the agricultural publication, *Pest & Crop Newsletter*.

Forensic entomological studies also use accumulated degree days extensively in their research, as temperature and insect development have a strong correlation (Anderson, 2000). For

use in these studies, entomologists developed an alternate calculation method that ties accumulated degree days to a given insect growth stage (Anderson, 2000). Some limitations exist with this method. The basic principle behind this correlation is an assumed linear relationship between temperature and development (Anderson, 2000). Insect development can be accelerated or delayed, however, by temperature extremes. Thus, the ADD that is needed to reach a certain stage of development can vary with differing temperatures, particularly temperature extremes (Anderson, 2000). This vulnerability to temperature extremes does not completely prevent use of this method; it simply requires that the forensic scientist be aware of how various temperatures will affect overall development and subsequently require a less linear calculation of accumulated degree days.

ADD is calculated by taking the high and low temperature of each day to find an average temperature for that day, and then finding the summation of each consecutive day (Miller, 2002). If the temperature falls below zero on any day, a value of zero is entered into the calculation; negative values are not used (Miller, 2002). Approximately 1285 +/- 110 accumulated degree days are required for a body to completely decompose, with complete decomposition defined as the cessation of volatile fatty acid production (Vass et al., 1992). In order to use accumulated degree days to estimate time since death, where the number of days is the unknown factor, Vass (1991) suggests measuring the average daily temperature over one week, and then dividing that into 1285 to determine a maximum number of days since death. This method becomes increasingly accurate the closer a body is to skeletonization, because it is more likely that the body will have been decomposing for a longer period of time (Miller, 2002).

**Accumulated Degree Hours (ADH)**

The increasing frequency of use of ADD, particularly in the entomological literature, prompted scientists to expand upon and refine the concept. Similar to ADD, accumulated degree hours also first appeared in agricultural studies (Greenberg and Kunich, 2002). The purpose of accumulated degree hours was to aid in finding the optimal time to apply insecticide to crops to limit agricultural pests (Greenberg and Kunich, 2002). This function is also dependent upon an assumed linear relationship between temperature and insect development. Determining the total ADH required for complete maturation of an insect requires adding the number of hours from egg to adulthood and multiplying that quantity by the temperature in degrees Celsius, after subtracting the developmental threshold temperature (Greenberg and Kunich, 2002). The developmental threshold temperature is the lower boundary; it is the temperature at which insect development will cease. The first application of ADH to a forensic case was a homicide from 1984 (Greenberg and Kunich, 2002). Entomologists in this case started with the total accumulated degree hours needed to reach full maturation for an insect species present at the crime scene and then subtracted each day's calculated ADH (by multiplying temperature by time) in order to work backwards and determine a likely date of oviposition for the insect species (Greenberg et al., 2002).

Since this initial use, some limitations to ADH have been noted. The most significant issue with accumulated degree hours revolves around the fact that the number of accumulated degree hours necessary for a given species to develop from egg to adult was determined in a scientifically controlled laboratory under precise conditions, and stable temperatures (Greenberg et al., 2002). Crime scenes, to the contrary, are very rarely in stable, controlled conditions, which

can affect the rate of insect development, and thereby confound a proper post mortem interval estimate. In addition, other environmental factors, such as submersion of maggots in water, presence of multiple species, or the presence of drugs in the corpse may all affect insect development and calculation of accumulated degree hours (Greenberg et al., 2002).

**Cumulative Degree Hours (CDH)**

Cumulative degree hours further refines the accumulated degree days concept. Accumulated degree days work well when describing longer post-mortem intervals, but have a potentially wide range. When discussing a body that has been decomposing for several months, the several days over or under-estimation given by accumulated degree days does not critically impact casework. Narrower estimating techniques are beneficial, however, when attempting to determine the post-mortem interval of a body that has been decomposing for a shorter period of time (Vass et al., 2002). In calculating CDH, the average temperature in degrees Celsius is added for each twelve hour interval in the decomposition process (Vass et al., 2002). Similar to calculation of accumulated degree days, temperatures below zero degrees Celsius are counted as a value of zero, and negative values are not used. Measuring the temperatures at smaller intervals allows for greater accuracy, but does limit the technique to cases in which the body has not been decomposing for an extended period of time.

## II. Materials and Methods

This study was conducted at the Anthropological Research Facility at the University of Tennessee, Knoxville. The facility consists of approximately 1.3 acres of wooded area, with minimal ground cover and primarily deciduous tree cover. A wooden fence surrounds the entire perimeter in order to prevent large scavengers such as canines from disturbing the remains contained within the research area.

Six fresh human cadavers were used in this research. Four of the cadavers were covered; two in plastic tarps and two in cotton thermal blankets. The purpose of covering the bodies was to create an intact internal shroud environment to compare to the external, ambient environment. To achieve this internal environment, body was first laid face up on the tarp or blanket, and the ends of the coverings were folded over the head and feet. The body was then rolled in the coverings to create a tightly wrapped shroud. Two bodies were placed uncovered on the ground surface as controls. The selection of materials was based on case reports of cadavers wrapped in plastic and blankets (Komar, 2003, Derrick 2007 personal communication). The cadavers were placed at the Anthropological Research Facility on May 29, 2008, at the same time to ensure that all were exposed to similar environmental conditions. The bodies were also placed as close to one another as possible to try and limit the amount of environmental variation between test subjects (Figure 1). Subjects were not protected by screening or wire mesh. This type of covering has traditionally been used to discourage animal scavengers. Part of the data collected discerned whether any of the coverings inhibited animal or insect activity, and therefore any barrier designed to protect the remains would have hindered this part of the study.


**Figure 1**: Positions of the cadavers at the ARF for the duration of research. Individuals 1 and 2 are in the background, Individuals 3 and 4 are in the foreground and Individual 6 is to the right. Individual 5 is to the left of the frame, just outside of the area captured in the photograph.

The cadavers were also of the same sex and ancestry, and the age range and body weight variation was kept as minimal as possible to avoid extraneous influences on the decomposition process. Individual demographic information on each of the individuals in the study will be collected at the time of placement. Age, sex, ancestry, weight, cause of death, and date of death was recorded, and is reported in Table 1.

In order to place the bodies at the same time, cadavers were kept in freezers in a small building at the facility until such time as six bodies were available for research. All research subjects were frozen for at least 48 hours prior to placement to avoid differential decomposition rates due to internal temperature differences at the beginning of research.

**Table 1:** Demographic information of individuals used in this study and date of placement into the freezer.

| ID number | Date Received at ARF | Age | Height (cm) | Weight (lbs) |
|---|---|---|---|---|
| 1 | 1/4/2008 | 77 | 165 | 164 |
| 2 | 2/22/2008 | 89 | 162.5 | 185 |
| 3 | 2/13/2008 | 68 | 163.5 | 113 |
| 4 | 2/12/2008 | 70 | 175 | 136.9 |
| 5 | 3/6/2008 | 49 | 169 | 138 |
| 6 | 3/15/2008 | 56 | 159 | 190 |

A dual-recording probe thermometer was placed at each body with the probe inserted into the soil underneath the body. Readings from the thermometers under shroud environments were considered experimental conditions, and ambient temperatures were taken at each body site from the main recording device in the display housing of the thermometer. Because temperature is one of the most important factors in determining the rate of decomposition (Mann et al., 1990), it is critical that accurate temperature data were collected to compare between the experimental and control samples. Temperature data collected included daily minimum and maximum temperature and two daily point comparisons. The maximum and minimum temperatures allowed for later calculation of accumulated degree days. The point comparisons were temperature readings collected daily at 8:30 a.m. and 4 p.m. These additional measurements provided more data for comparison between the experimental and control conditions, which made the statistical analyses more robust.

The bodies remained covered and undisturbed for thirty days. At the end of that period, the bodies were uncovered, the amount of decomposition was scored as described below, and the presence or absence of insect activity was noted. Any disturbance of the bodies due to animal activity or weathering was also recorded. All data collected on each individual was recorded in both written and photographic form and all photographs were labeled by individual number.

Using the recorded temperature data, the accumulated degree days (ADD) were calculated and compared to the actual number of days postmortem. Accumulated degree days are calculated by averaging the high and low temperatures for each day postmortem, and then summing the averages after the method discussed in Vass, 1991. Although extremely low temperatures can severely inhibit or even temporarily cause cessation of the decomposition

process, this was not a factor for this project since all data collection took place during the summer months.

Although the reliability of using ADD to determine the post-mortem interval has been shown to be inconsistent, this technique will provide a standard basis of comparison between the temperature data recorded from each individual and how it affects decomposition, particularly in the earliest stages. In addition, calculation of ADD is necessary to evaluate the accuracy of the predictive methodology developed by Megyesi et al. (2005) in situations where the body in question has been covered during decomposition.

Following Megyesi (2001), the amount of decomposition on the body was scored for each of three areas. These areas include 1) the head and neck, 2) the trunk and 3) the limbs (Megyesi, 2001). Each of the three areas is given a numerical score based on the amount of decomposition present at that location (Megyesi, 2001). The scales for each section are outlined in Tables 2, 3 and 4. Images 2, 3, 4, and 5 illustrate features common to each general category.

Table 2- Categories and stages of decomposition for the head and neck

---

A. Fresh

(1 pt) 1. Fresh, no discoloration

B. Early decomposition

(2 pts) 1. Pink-white appearance with skin slippage and some hair loss.

(3 pts) 2. Gray to green discoloration: some flesh still relatively fresh.

(4 pts) 3. Discoloration and/or brownish shades particularly at edges, drying of nose, ears and lips.

(5 pts) 4. Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present.

(6 pts) 5. Brown to black discoloration of flesh.

C. Advanced Decomposition

(7 pts) 1. Caving in of the flesh and tissues of eyes and throat.

(8 pts) 2. Moist decomposition with bone exposure less than one half that of the area being scored.

(9 pts) 3. Mummification with bone exposure less than one half that of the area being scored.

D. Skeletonization

(10 pts) 1. Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.

(11 pts) 2. Bone exposure of more than half the area being scored with desiccated or mummified tissue.

(12 pts) 3. Bones largely dry, but retaining some grease.

(13 pts) 4. Dry bone.

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*Reprinted with permission from Megyesi, 2001*

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Table 3- Categories and stages of decomposition for the trunk.

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

*Reprinted with permission from Megyesi, 2001*

Table 4 - Categories and stages of decomposition for the limbs.

A. Fresh

(1 pt) 1. Fresh, no discoloration.

B. Early decomposition

(2 pts) 1. Pink-white appearance with skin slippage of hands and/or feet.

(3 pts) 2. Gray to green discoloration; marbling; some flesh still relatively fresh.

(4 pts) 3. Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities.

(5 pts) 4. Brown to black discoloration; skin having a leathery appearance.

C. Advanced Decomposition

(6 pts) 1. Moist decomposition with bone exposure less than one half that of the area being scored.

(7 pts) 2. Mummification with bone exposure of less than one half that of the area being scored.

D. Skeletonization

(8 pts) 1. Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining.

(9 pts) 2. Bones largely dry, but retaining some grease.

(10 pts) 3. Dry bone.

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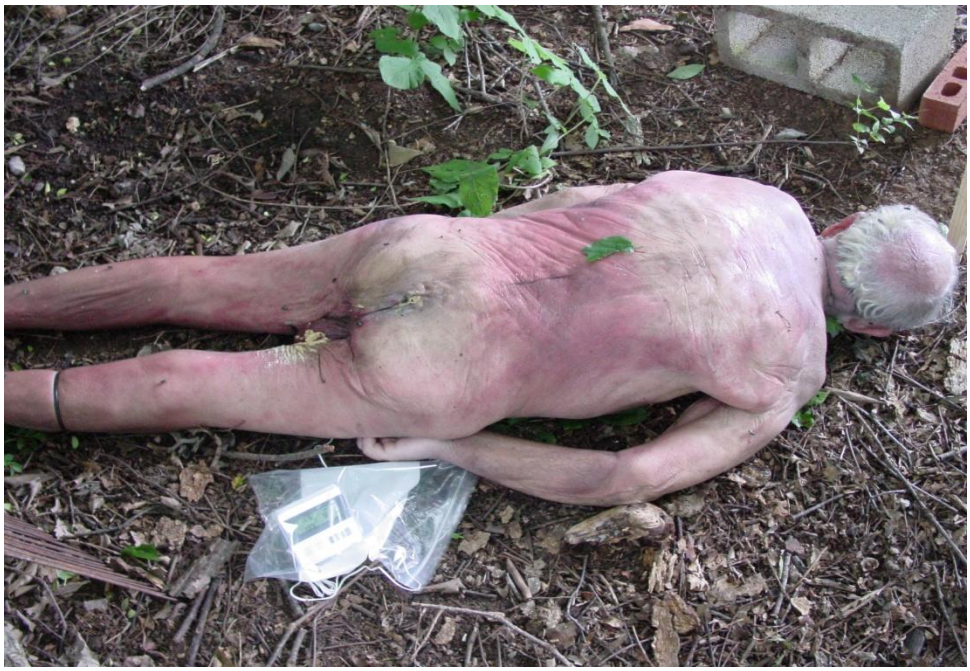

**Figure 2:** A body in the "fresh" stage showing areas of no discoloration.

**Figure 3:** A body in the "early decomposition" stage showing skin slippage on the hands, brown discoloration of the limbs, and marbling on the dorsal surface.

**Figure 4:** A body in the "advanced decomposition" stage showing post-bloating with the sagging in of skin in the abdominal area, and mummified tissue with little to no bone exposure.

**Figure 5:** A body in the "skeletonization" phase, showing bone exposure over half the area being scored, with little to no soft tissue remaining.

Based on this total body decomposition score, Megyesi (2001) and Megyesi et. al (2005) propose a method to estimate the accumulated degree days without collecting temperature data. The formula for predicting ADD based on total body decomposition is as follows:

$$ADD = 10^{(.002*TBS*TBS+1.81)} \pm 388.16$$

where TBS is total body decomposition score and 388.16 is the "standard error of the regression in untransformed (non-logged) ADD's" (Megyesi et al., 2005).

A multiple linear regression was used to determine if the ADD calculated following Megyesi et al. (2005) produced a good estimation of the ADD calculated following Vass (1991), considered to be the actual ADD. An analysis of variance (ANOVA) was also run on the total body decomposition scores to determine if there was a significant difference in the amount of decomposition between bodies exposed to different treatments, and if decomposition was constant within treatments. Following the methods of Megyesi (2001) calls for adding together the scores obtained from the head, torso, and limbs to calculate a total body decomposition score. In this analysis, the scores from each area of the body were analyzed before they were cumulated in order to test the different areas of the body separately in addition to total decomposition.

A repeated-measures ANOVA was run on the collected daily point comparison temperatures to determine if there was a statistically significant difference in the ambient versus the shroud environment temperatures, and also to determine if differences in temperature existed between treatments. All statistics were computed using NCSS statistical software (Hintze, 2007).

## III. Results

### General observations

Insect activity did appear to be affected by the coverings, as the uncovered bodies on the surface were the first to show evidence of insects. Location of the bodies also appeared to have some effect on the insect activity even though the bodies were placed relatively close together and in similar conditions. The bodies which had more sun exposure took longer to display insect activity than those bodies in the shadier areas.

### Individual 1: Surface

Days were numbered starting with the day after placement and wrapping at the ARF. By the afternoon of Day 1 some initial signs of decomposition were present, including marbling on the legs and some fly activity around the head (Figure 6). By Day 2 the marbling was also apparent on the arms, and some skin slippage was noted. Fly activity was also much more prevalent. Maggot activity was first noted on Day 4, and appeared to peak around Day 8 (Figure 7). Bloat was noted on Day 6. By Day 8, skin slippage was evident across the entire body, and very little if any of the epidermis was still present. Some bone exposure was noted on the skull. After this point, fluid expulsion was noted and maggot activity decreased steadily until Day 18 (Figure 8), when no maggot activity was observable and no color changes, fluid loss or other signs of progression of the decomposition process were noted. Mummification was noted by Day 22, and little to no change was noted from that day through completion of the data collection on Day 31 (Figure 9).

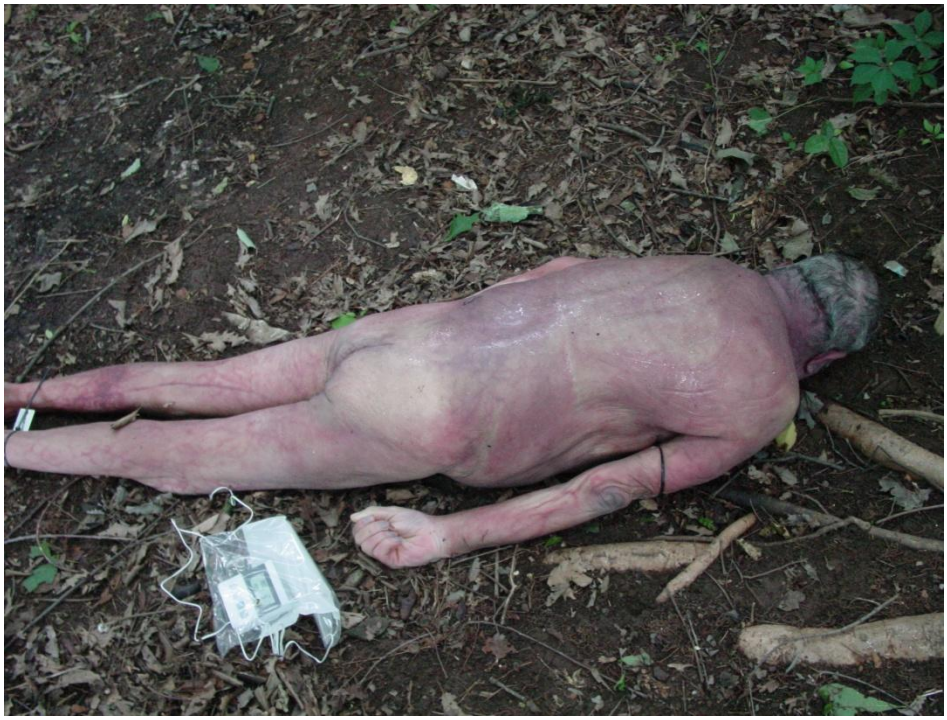

**Figure 6:** Individual 1 on Day 1 showing little discoloration or signs of decomposition. Purplish stains on the legs consistent with marbling are noted on the legs.

**Figure 7:** Individual 1 on Day 8, at peak of maggot activity.

**Figure 8:** Individual 1 on Day 18. The skin has become leathery and sunken in, and no further decompositional changes were noted after this date through research conclusion.


**Figure 9:** Individual 1 on Day 31 at end of data collection. Moist decomposition was noted on the ventral surface and much of the dorsal skin remained dried and intact.

**Individual 2: Surface**

Individual 2 was the first to show insect activity, with egg masses and flies present by the end of Day 1 (Figure 10). A purplish discoloration was noted on the back and legs by the end of that day as well. Day 2 involved more fly activity, marbling on the arms, and the beginning of skin slippage. By Day 3 the fly activity had lessened, but maggot activity was noted along with additional skin slippage. By Day 5 color changes were seen throughout the body, skin slippage was noted on the hands, legs, and feet, and the body had entered the bloat stage. Maggot activity peaked at Day 8 (Figure 11), coinciding with the first observation of fluid loss. From there, the maggot activity slowly declined, bloating ceased and fluid loss continued until Day 14, when the process appeared to stabilize. A second wave of maggot activity was noted on Day 16, along with bird activity concentrated at the head. By Day 18 (Figure 12), insect activity had almost completely subsided, and little change was seen until Day 21. After Day 21, a yellow mold was observed on the back, and dessication of the tissues was apparent. The skin appeared mostly mummified, and remained relatively unchanged from this point through Day 31(Figure 13).

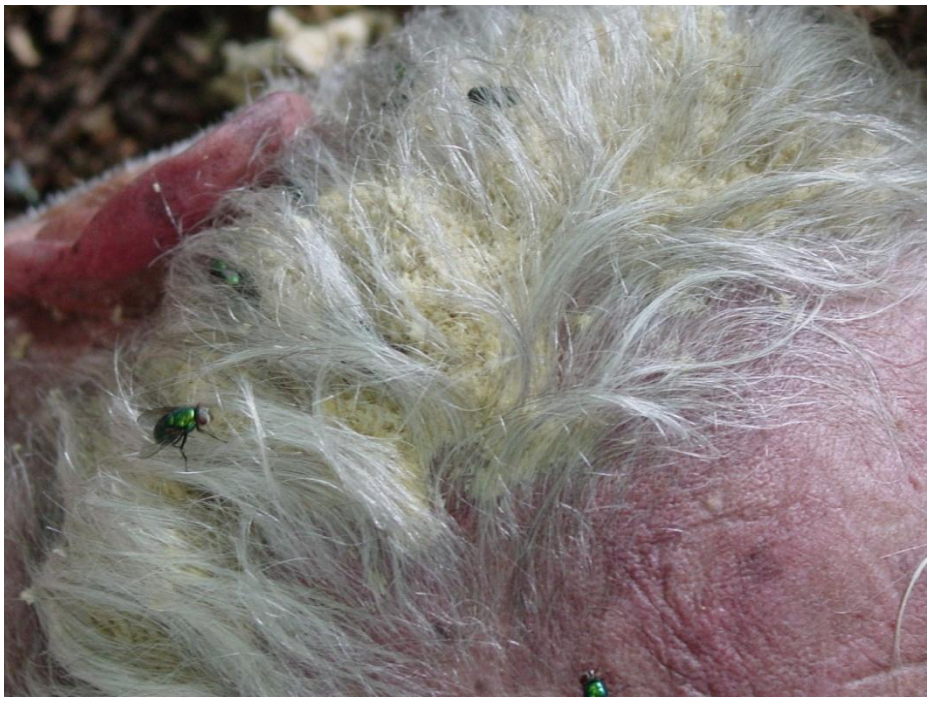

**Figure 10:** Individual 2 on Day 1 showing egg masses in the hair and pink to white discoloration of the skin.

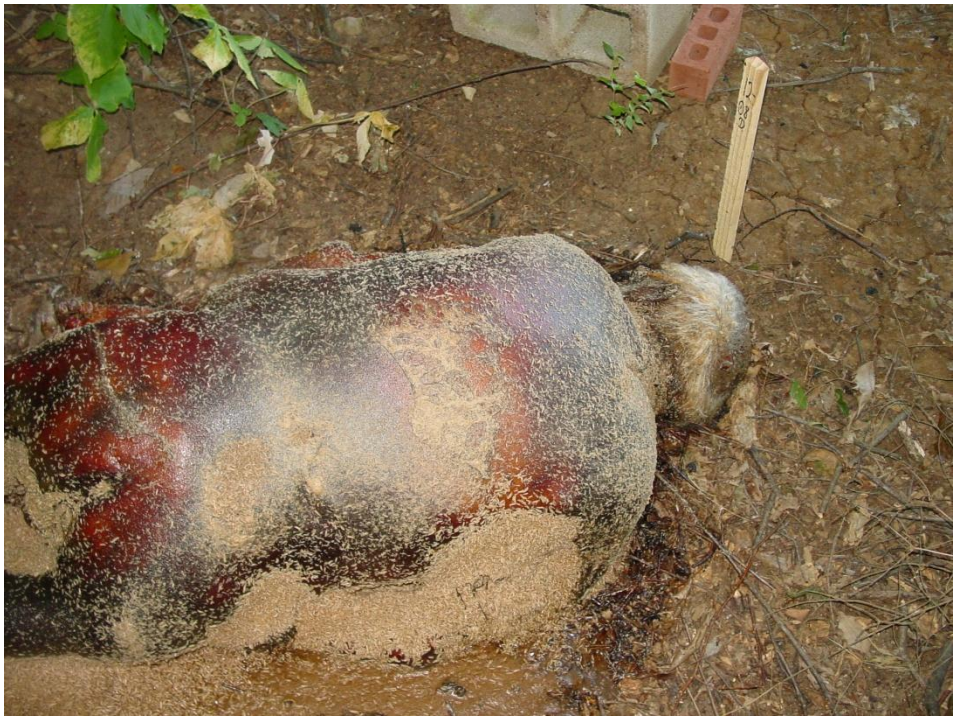

**Figure 11:** Individual 2 on Day 8 illustrating maggot activity, with brown to black discoloration of the soft tissue.

**Figure 12:** Individual 2 on Day 18, showing caving in of the dorsal surface, and widespread brown to black discoloration.

**Figure 13:** Individual 2 on Day 31showing moist decomposition on the ventral surface.

**Individual 3: Cotton Blanket**

Figure 14 shows Individual 3 on Day 1, when no decompositional changes were seen. Little insect activity was noted on Individual 3 until Day 3, in which a few bugs were noted near the head, and some small stains were seen on the blanket. The insect activity remained minimal, and the only visible sign of decomposition was staining on the blanket until Day 6, when the body entered the bloat stage and fluid loss was seen. More obvious staining along with fly and beetle activity was seen on Day 8 (Figure 15). The first maggot activity was not seen until Day 9, and was localized to the neck area. Maggot activity increased over the next three days, mainly in the head and arm areas. Staining also became much more prevalent. By Day 12 the staining was almost continuous from the head to the feet, and maggot activity was widespread. By Day 18 (Figure 16), the blanket began to sink and flatten out around the head, a distinct odor was noted, and bloat was observed. Insect activity continued, with ants being the primary species observed. Bloat began to lessen by Day 22, and insect activity ceased by the next day. Bird activity was noted after this point, and debris such as twigs and leaf litter continued to collect on the body through the end of data collection. When the body was uncovered on Day 31, it was apparent that the body had mummified, with even facial hair being preserved (Figure 17).

**Figure 14:** Individual 3 on Day 1.

**Figure 15:** Individual 3 on Day 8, with staining apparent on the cotton blanket.

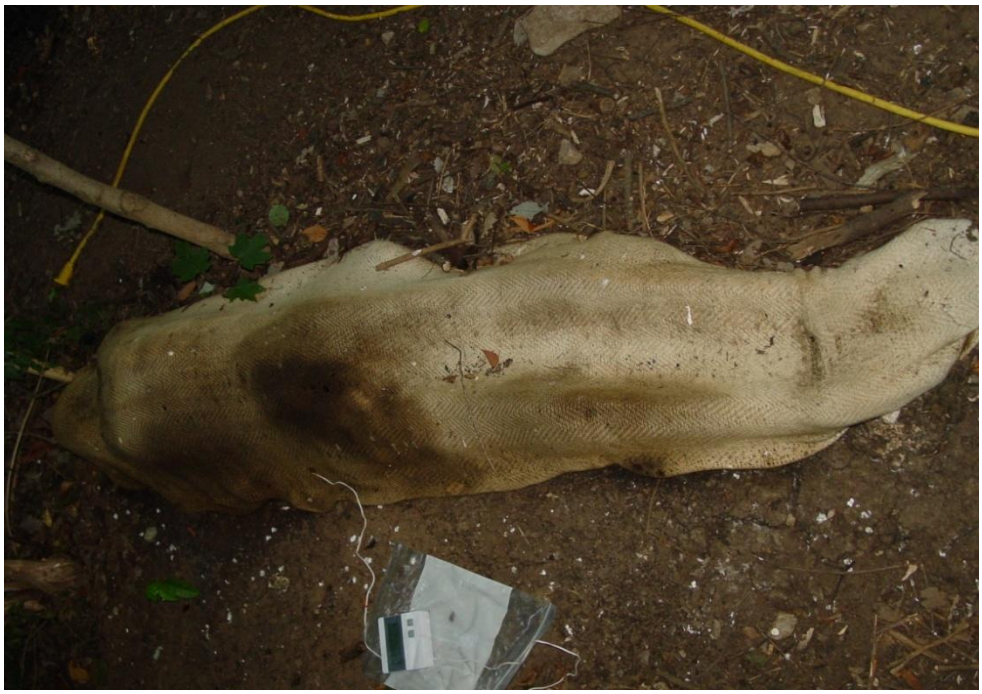

**Figure 16:** Individual 3 on Day 18, showing widespread staining from decompositional fluids,and flattening out of the blanket post-bloat.

**Figure 17:** Individual 3 on Day 31 with widespread mummification.

**Individual 4: Cotton Blanket**

Ants, spiders and some flies were noted on the body on Day 1 (Figure 18), and insect activity continued the next day, when stains were also observed on the arms and head. By Day 4 the insect activity had increased to heavy fly activity and black stains were seen on the head. Maggots were observed on the head on Day 5, staining was noted on the arms, and ants were observed on the torso. Bloat was observed on Day 6, and staining covered the head, upper torso and arms. Flies, ants and beetles were all observed on the body. Fluid leaking was first observed on Day 8 (Figure 19). Bloat began to decrease on Day 8, and more fluid loss was noted. Maggot activity peaked on Day 9, along with near continuous staining and massive fluid loss. By Day 13 most insect activity had ceased, and the same odor was noted as the one being emitted from Individual 3. By Day 18, debris was seen gathering on the blanket (Figure 20). After this point, no gross changes were noted other than debris collecting on and around the body through Day 30. Once the body was uncovered, it was apparent that this individual had also mummified. However, unlike Individual 3, bone exposure was noted on Individual 4 throughout the body, and some saponification was noted in the chest area (Figure 21).

**Figure 18:** Individual 4 on Day 1 with no decompositional changes noted.

**Figure 19:** Individual 4 on Day 8, showing staining, maggot activity and bloat.

**Figure 20:** Individual 4 on Day 18 with debris such as leaf litter and twigs gathering on and near the blanket.

**Figure 21:** Individual 4 on Day 31 showing moist decomposition on the ventral surface and mummification on the limbs, dorsal surface and head.

**Individual 5: Tarp**

Day 1 (Figure 22) showed no decompositional changes. Water was observed collecting on the outside of the tarp, but no indicators of decomposition were observed until Day 4. On that day, some fly activity could be seen around the tarp, and flies could be heard buzzing on the inside of the tarp. Flies continued to be observed for the next few days, and on Day 6 the body appeared to be in bloat and a strong odor was emanating from the body. Small maggots were observed on the tarp on Day 8 (Figure 23) and were primarily noted at the thermometer probe insertion point and at the head end of the tarp. Maggot activity and bloat began to decrease on Day 10. This pattern continued until Day 18, when fluid was observed seeping from the probe insertion point (Figure 24). Evidence of birds was noted on the following three days. Beyond Day 22 no obvious changes were observed beyond increased leaf litter on the tarp. When the tarp was opened on Day 31, massive saponification was noted throughout the body, and much of the body was still fleshed (Figure 25). Bone exposure was noted only on the tibiae, fibulae and feet. Large masses of soldier fly maggots were also observed inside the tarp and on the body.

**Figure 22:** Individual 5 on Day 1 showing no decompositional changes.

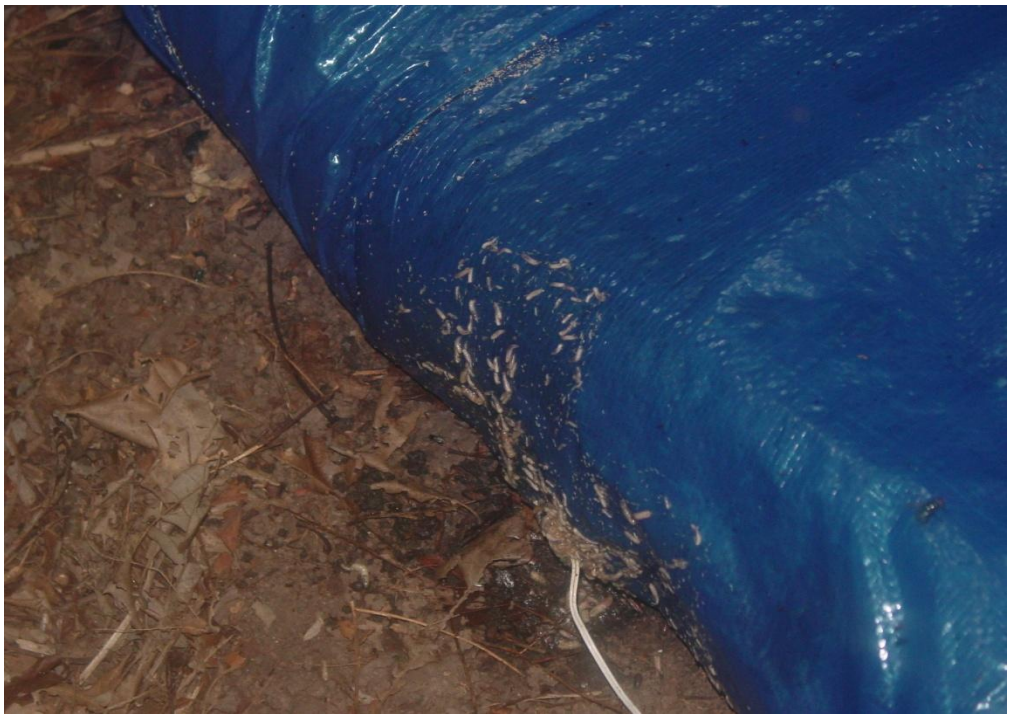

**Figure 23:** Individual 5 on Day 8 with maggot activity at the probe insertion point.

**Figure 24:** Individual 5 on Day 18 with decompositional fluids leaking from the probe insertion point.

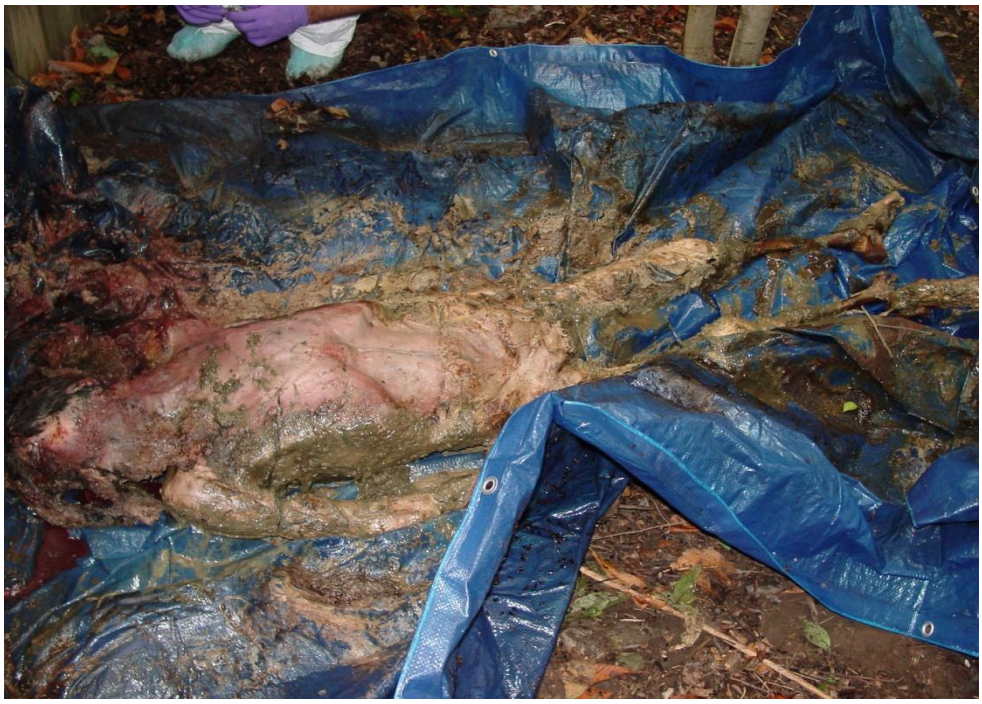

**Figure 25:** Individual 5 on Day 31 with large scale saponification and soft tissue decomposition. Bone exposure was noted on the lower limbs.

**Individual 6: Tarp**

Day 1 showed no changes (Figure 26). Insect activity was noted on Day 3, and flies could also be heard inside the tarp. By Day 5 fluid was observed leaking from the end of the tarp near the head, and flies were still present. Heavy maggot activity localized to the head was observed on Day 6, and also on this day the head of Individual 6 had been pushed out of the end of the tarp and was clearly visible. Bloat was observed that afternoon. Maggot activity was noted on the head and at the feet over the next four days, peaking around Day 8 (Figure 27). Bloat began to decrease on Day 10, although heavy maggot activity continued through Day 14, when the majority of the maggot activity was seen in the soil surrounding the body. Fluid loss was also noted at this point. Tissue on the head continued to decay over the next few days, resulting in bone exposure and gnat activity. Similar to Individual 5, bird activity was observed. Past Day 18 very little change was noted (Figure 28). When the body was uncovered, the skull was mostly skeletonized, with some desiccated tissue still observed. Moist decomposition was noted in the abdominal region, legs and feet, with some bone exposure observed on the tibiae and fibulae (Figure 29).

**Figure 26:** Individual 6 on Day 1.

**Figure 27:** Individual 6 on Day 8 showing large amounts of maggot activity at the end of the tarp.

**Figure 28:** Individual 6 on Day 18, showing fluid loss and exposure of the skull.

**Figure 29**: Individual 6 on Day 31 showing saponification, widespread soft tissue decomposition, and skeletonization of the skull.

**Temperature Trends**

Some of the treatments appeared to have constantly shifting daily temperatures, while other treatments appeared to maintain more stable temperatures. Maximum and minimum temperatures also varied between treatments. (See Figures 20-25 for mean daily temperatures taken from inside the shroud or under the body for each individual.) The difference in temperature pattern can be seen most clearly in Figure 26, which shows the mean daily temperatures for all of the individuals superimposed together for comparison.

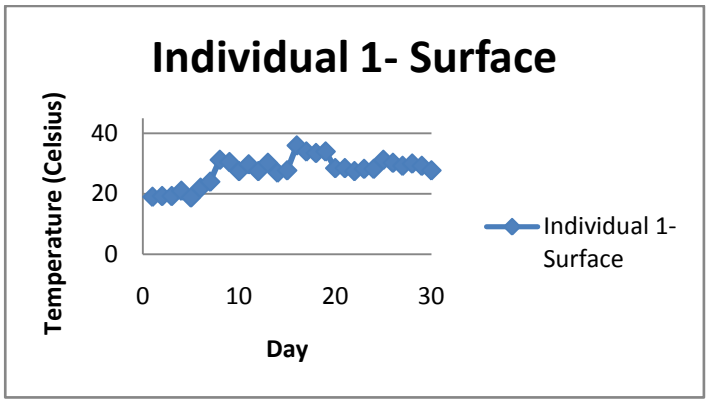


**Figure 30**: Graph of mean daily under body temperatures for Individual 1.

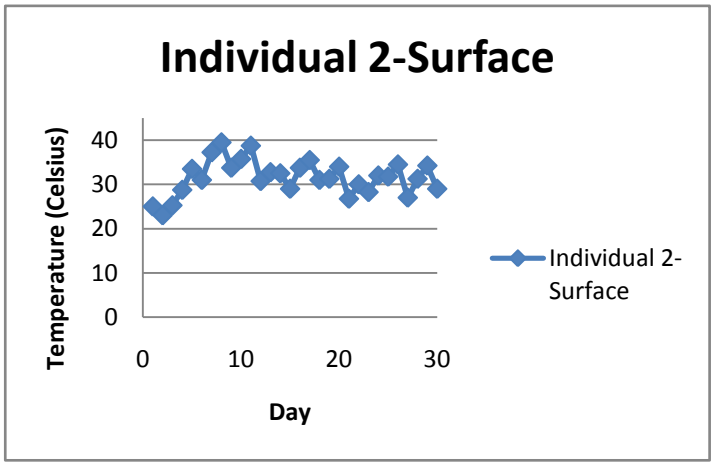


**Figure 31**: Graph of mean daily under body temperatures for Individual 2.

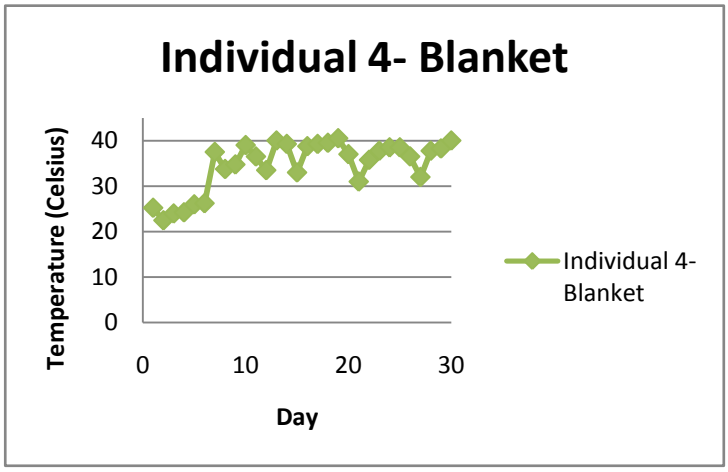


**Figure 32**: Graph of mean daily inside shroud temperatures for Individual 3.

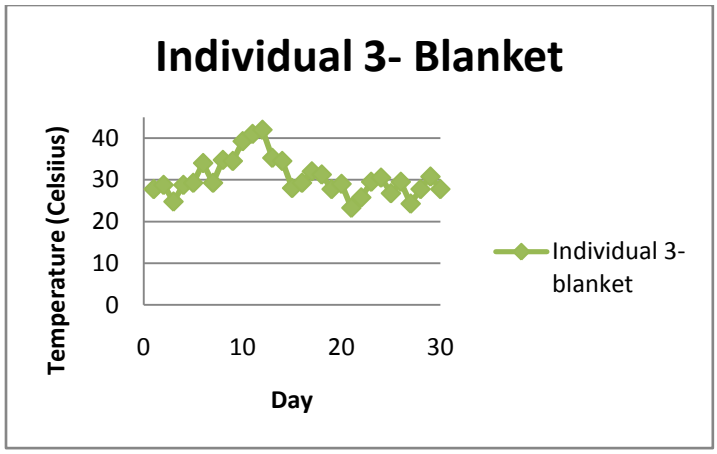


**Figure 33**: Graph of mean daily inside shroud temperatures for Individual 4.

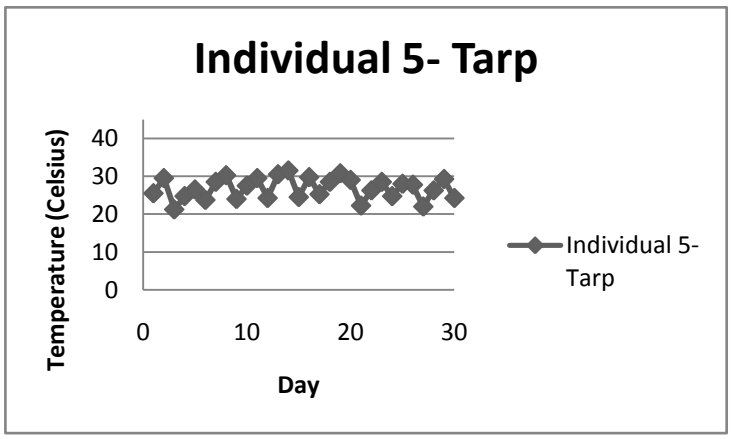


**Figure 34**: Graph of mean daily inside shroud temperatures for Individual 5.

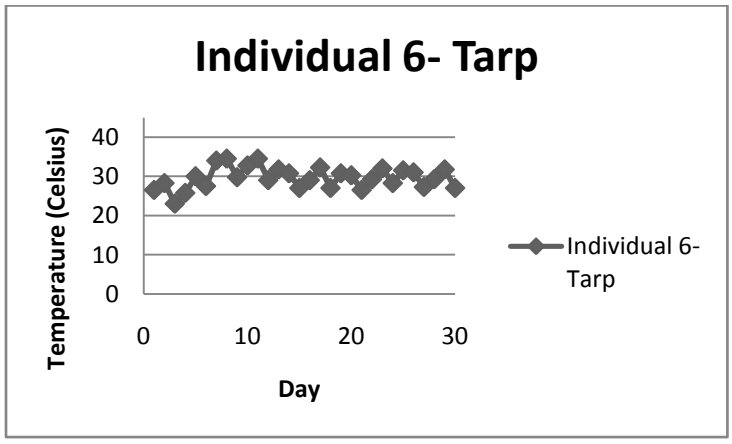


**Figure 35**: Graph of mean daily inside shroud temperatures for Individual 6

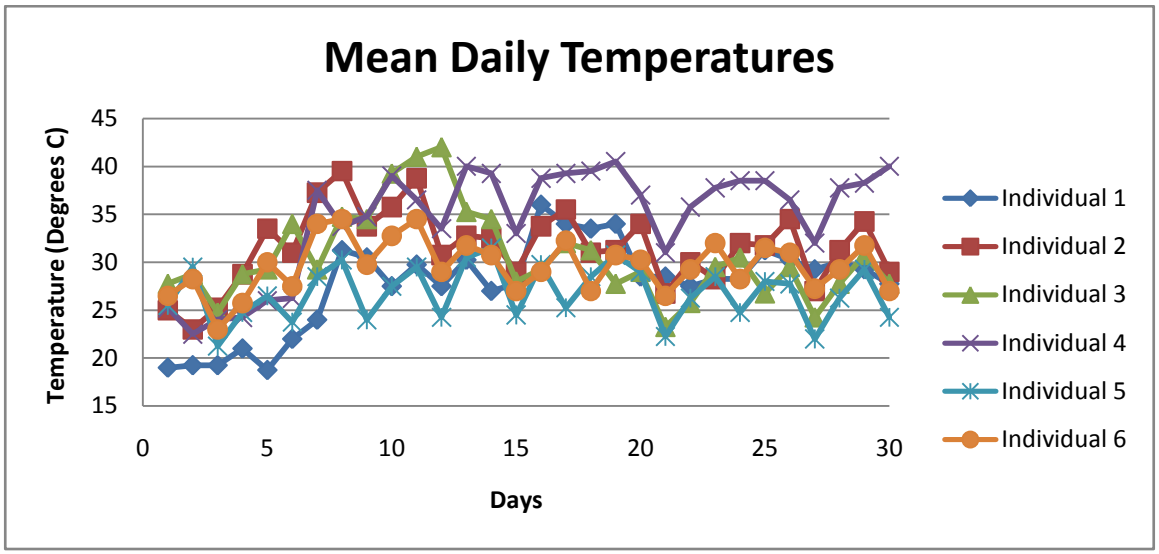


**Figure 36**: Graph of mean daily inside shroud/under body temperatures for Individuals 1-6.

**Multiple Regression**

Both methods of estimating accumulated degree days were regressed against the actual accumulated degree days in order to determine which method of estimation performed better. The r –square value for the estimation following Megyesi et al. (2005) was .8567 with three degrees of freedom, which indicates that estimated accumulated degree days based on total body decomposition was strongly correlated with the actual ADD when accounting for the various treatments. This model was not found to be significant at alpha equal to .05 (Table 5).

| Independent Variable | Regression Coefficient | Standard Error | d.f. | p-value | $R^2$ | Adj$R^2$ |
|---|---|---|---|---|---|---|
| Intercept | 667.0107 | 26.5513 | 1 | 0.0016 | | |
| Blanket | -5.2819 | 11.7224 | | 0.6964 | | |
| Est_1 | 0.0639 | 0.0276 | | 0.1472 | 0.8567 | 0.6418 |
| Tarp | 54.3480 | 16.6275 | | 0.0822 | | |
| Model | | | 3 | 0.2071 | | |
| Error | | | 2 | | | |

**Table 5:** Multiple Regression for ADD estimation based on Megyesi et al. (2005).

| Independent Variable | Regression Coefficient | Standard Error | d.f. | p-value | $R^2$ | Adj$R^2$ |
|---|---|---|---|---|---|---|
| Intercept | 604.5943 | 139.9434 | 1 | 0.0496 | | |
| Blanket | 15.8003 | 24.2289 | | 0.5813 | | |
| Est_2 | 0.1259 | 0.1451 | | 0.4770 | 0.6183 | 0.0457 |
| Tarp | 48.2352 | 31.4313 | | 0.2645 | | |
| Model | | | 3 | 0.5139 | | |
| Error | | | 2 | | | |

**Table 6:** Multiple Regression for ADD based on under-shroud temperature.

The second method tested used the temperatures collected from inside the shroud or underneath the control bodies to calculate ADD. This estimation method did perform well, as the r-squared value was 0.6183 with three degrees of freedom when accounting for the different treatments. This demonstrates that there is a strong correlation between the estimated and actual values. However, the model was not found to be significant (Table 6).

The multiple linear regression results indicated that the estimation of ADD based on decomposition scores produced a more highly correlated estimate with the calculated ("actual") ADD than did the estimated ADD based on inside-shroud temperatures. However, wide disparities were noted between individuals subjected to different treatments. Individual 5, for example, had a much lower estimated ADD using the Megyesi (2005) method than with either the calculated ADD or the estimated ADD using the inside-shroud temperatures (see Table 7)

**Table 7:** ADD Scores at 30 days Calculated Following Megyesi (2005) and Inside-Shroud Temperatures which were used in Regression Analysis

| ID | Treatment | Actual ADD | Megyesi estimate | Inside-Shroud Estimate |
|---|---|---|---|---|
| 1 | None | 716.5 | 916 | 981 |
| 2 | None | 734.5 | 916 | 939.75 |
| 3 | Blanket | 714 | 916 | 854.25 |
| 4 | Blanket | 741.25 | 1148 | 849.25 |
| 5 | Tarp | 737.5 | 210 | 697.5 |
| 6 | Tarp | 766.75 | 738 | 872 |

This discrepancy may be partly because the different treatments produced decompositional changes which did not fit with any of the pre-defined categories. Although mummification was considered in the calibration sample of Megyesi (2005), there was no specific score to assign in the case of complete mummification, and Individuals 5 and 6 did not fit well into any of the scoring criteria. Individual 6 presented a particularly difficult scenario, as the body and the head effectively decomposed in different environments.

To further investigate the relationship between ADD estimated from total body decomposition scores, more analysis was completed with individuals 1 and 2. These two bodies were uncovered, and so it was possible to review daily photographs and assign a daily total body decomposition score, which was then used to calculate the daily ADD. Figure 27 shows the plotted daily ADD by the daily total body decomposition scores. It is notable that both series for Individuals 1 and 2 increase in estimated ADD rapidly and then are held constant after Day 18.

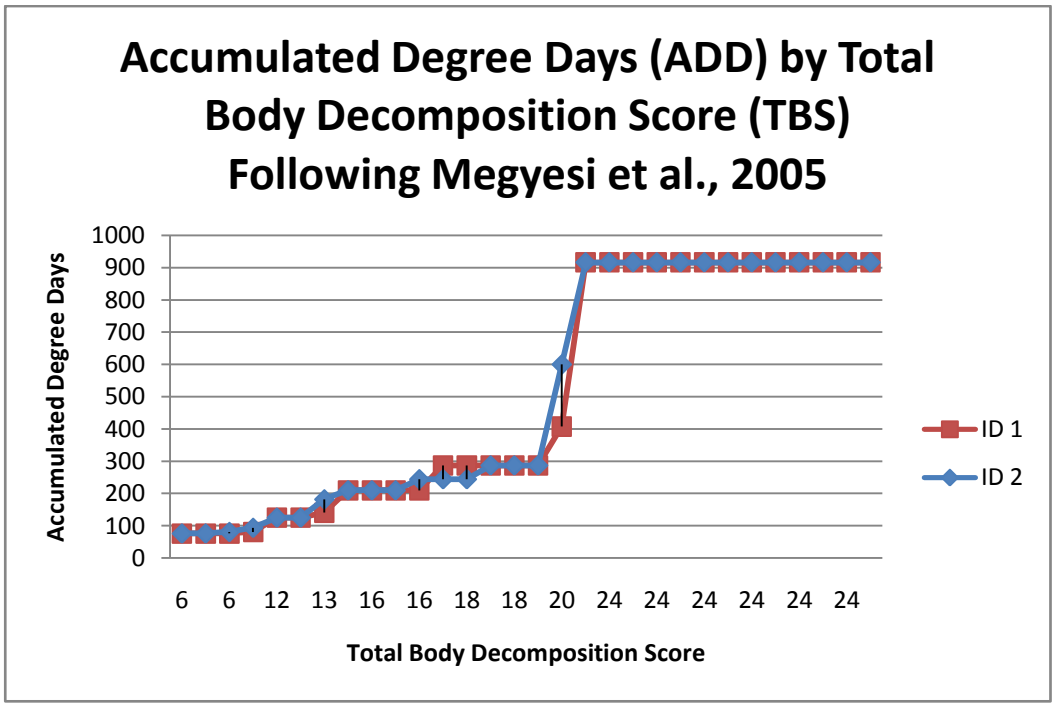


**Figure 37**: Plotted daily ADD versus daily total body decomposition scores for Individuals 1 and 2.

**Analysis of Variance (ANOVA)**

A repeated measures analysis of variance was conducted to determine if temperature differences existed between the ambient temperatures and the under-body temperatures. This difference was found to be significant (Table 8). In this table, the term "type" refers to the type of temperature measurement taken, either from under the body/inside the shroud, or the ambient measured temperature. "Treatment" refers to the covering in which the body was wrapped, or in the case of the controls, the lack of a covering. The term "time" is used to specify the time of day at which the measurement was collected, either morning or afternoon.

**Table 8**: ANOVA results for differences in temperature between individuals adjusted for treatments (between treatments)

| Source Term | DF | Sum of Square Error | Mean Square Error | F-Ratio | p-value |
|---|---|---|---|---|---|
| Type | 1 | 6215.75 | 6215.75 | 26.25 | 0.014393 |
| Treatment | 2 | 1329.678 | 664.8389 | 1.75 | 0.31343 |
| Time | 1 | 4236.476 | 4236.476 | 247.01 | 0.000560 |
| Error | 696 | | | | |

Temperature differences were also examined between individuals subjected to the different treatments, or coverings. These differences were not found to be significant. The difference between temperatures taken in the morning versus in the afternoon was also examined, and this was found to be significant.

A general linear model ANOVA was run on the raw body decomposition scores to determine if differences in the amount of decomposition existed. The analysis was set up to examine the head, torso, and limbs separately, in addition to the total body decomposition score. Significant differences were found in the scores of the torso, but none of the other areas were shown to have statistically significant differences (Table 9).

**Table 9**: ANOVA results for body decomposition scores adjusted for treatment.

| **Response Variable** | **DF** | **Sum of Square Error** | **Mean Square Error** | **F-Ratio** | **p-value** |
|---|---|---|---|---|---|
| Head | 2 | 1.33 | 0.67 | 0.50 | 0.649519 |
| Error for Head | 3 | 4.00 | 1.33 | | |
| Torso | 2 | 4.33 | 2.17 | 13.00 | 0.033272 |
| Error for Torso | 3 | 0.50 | 0.17 | | |
| Limbs | 2 | 1.33 | 0.67 | | |
| Error for Limbs | 3 | 0.00 | 0.00 | | |
| Total Body Score | 2 | 7.00 | 3.5 | 4.20 | 0.134997 |
| Error for TBS | 3 | 2.50 | 0.83 | | |

## IV. Discussion

Observations made on the rates of decomposition between bodies exposed to different coverings did not produce the same conclusions as the statistical analyses. While it appeared from visual inspection that differences in rates of decomposition did exist between treatments, no statistically significant differences were found between bodies subjected to different treatments. This discrepancy between the statistical analysis and the visual analysis may stem from the fact that the statistics were meant to analyze differences in temperature specifically, and although temperature was used as a measurable proxy for decomposition, it does not cover all factors involved. Another key factor may have been that the statistical analyses used looked at the difference in temperature degrees on a point-by-point individual comparison basis, while the analysis of decomposition based on visual changes looked at the overall change from the start of the process to the end, instead of measuring daily change. This then renders the two types of analyses more difficult to compare and reconcile.

### Statistical Analysis

The repeated-measures ANOVA was used to determine whether differences in temperatures existed between treatments, between measurements taken in the morning and the afternoon, and between the ambient versus the inside shroud environment temperatures. While significant differences were identified between time of measurement and between ambient and inside shroud temperatures but not between treatments. The differences in morning and afternoon temperatures were clearly more disparate than between either the ambient and inside shroud environment or between the treatments. However, the exact difference in degrees between the temperatures is perhaps only part of the pattern which needs to be explained in order

to account for the apparent differences in decomposition. Another key factor seems to be the overall trend of the temperatures in the 30 day period as a whole. Part of the issue with the statistical analyses also lies in the fact that they were only examining temperature differences. Although temperature is a major impacting factor in the rate of decomposition, it is far from the only variable that can have an effect. Variables such as moisture content within the different shroud environments could also have produced differential rates.

**Decompositional Differences**

Individuals 1 and 2, both of which were surface placements, displayed the least amount of differences in decomposition during the course of this project. Both of the individuals showed some bone exposure by Day 31, and the majority of the tissue on the back of the body and on the limbs was desiccated. However, insect activity was present on Individual 2 approximately 24 hours prior to Individual 1, which may have been due to differences in internal temperature after the freezing process. Although both individuals were placed in the freezers at the same temperature, Individual 2 may have reached a higher internal temperature more quickly than Individual 1, and would have therefore been a more suitable envrionment for insect activity.

Another noticeable difference was the presence of a yellowish mold on Individual 2 that did not occur on Individual 1. The source of this mold is unknown. The development localized to one  body and not the other may have been a product of different placement environment. However, this difference is a relatively insignificant one, as it did not appear to have a major effect on the decomposition process as a whole.

Individuals 3 and 4 also did not show identical decompositional progress. Although both bodies were mummified by the end of the data collection period, Individual 3 was noticeably

better preserved. Individual 4 also displayed more maggot activity earlier in the decomposition process, and wide-scale staining was apparent several days earlier to any staining on the blanket of Individual 3. These differences may have been due in part to location; Individual 3 was in an area with more sun exposure, which may have helped to keep the body at a higher temperature, and which would have helped to keep the area drier. In contrast, Individual 4 was placed at the base of a large tree, was mostly in the shade, and was in relatively damper soil.

Differences were also noted between individuals 5 and 6, both of which were wrapped in plastic tarps. The most noticeable difference between the two individuals was the bone exposure on the skull of individual 6. This rapid decomposition can most likely be attributed to the fact that the skull of individual 6 did not remain covered by the tarp for the duration of the project. This exposure of the head of Individual 6 to the outside environment may have been due to a tighter wrapping of the tarp around the body than was done on Individual 5. The skull was not seen protruding from the tarp of Individual 6 until after the body had entered the bloat stage. This may indicate that the tight wrapping left the body less room to expand during bloat and thus forced the body to shift against the end of the tarp, pushing the head out of the covering. Another factor which may have contributed to the head being exposed was the fact that Individual 6 was placed on more of a slope than Individual 5, with the head at the downward end of the slope. This may have facilitated the movement of the body toward the end of the tarp during bloat and led to the bone exposure.

Differences in decomposition were clearly seen between individuals exposed to the different experimental treatments. While the bodies on the surface and the bodies in cotton blankets both showed desiccated tissue and mummified tissue, the extent of mummification was

much more prevalent on Individuals 3 and 4. In addition, the undersides of Individuals 1 and 2 which had been in contact with the soil for the duration of the project showed much more bone exposure and moist decomposition than was evident on either of the bodies which had been shrouded in cotton.

Individuals 5 and 6 which were encased in the plastic tarps showed perhaps the most dramatic differences in decomposition of any of the experimental bodies. The most striking difference was the amount of moist decomposition and soft tissue remains that were found on Day 31. There was no evidence of mummification, and even areas of the body that showed bone exposure did not have any desiccated tissue. Also, none of the other bodies had close to the amount of adipocere seen on Individuals 5 and 6, and they were also the only bodies to still have insect activity by the end of the data collection period.

**ADD Estimation Methods**

Two methods of estimating the post-mortem interval (PMI) were tested during this analysis. While no statistically significant differences were found between the estimated ADD and the actual ADD, the estimations produced did vary, possibly enough to be a confounding factor if used in a forensic setting.

Tests of the Megyesi method showed that while the technique is effective in many cases and easy to implement, it is not well tailored to all possible settings that could be encountered in a forensic context. Using this method to estimate ADD for the bodies in the plastic tarps was the most difficult, as the decompositional changes seen in these cases did not conform well to the decompositional indicators presented in the Megyesi method. ADD estimated for Individual 6 was not widely different from the actual ADD, but this is only because the head skeletonized and

thus increased the overall TBS. Had the body remained entirely encased in the tarp as planned, it is likely that the score would have been more similar to that for Individual 5.

The estimation method using the under-body or inside shroud temperatures produced similar ADDs for all individuals to the ADDs calculated according to Vass (1991) which suggests that no real adjustment is needed for covered bodies. The intent behind collecting the inside-shroud temperatures was to calculate a more precise ADD, but this was not achieved. Given that determining what the inside-shroud temperatures would be for a covered body in a forensic context would be complicated and require correction factors, it does not seem practical when the traditional methods or the Megyesi method provide an equal or better estimation.

**Considerations for Future Research**

Problems with this research included a small sample size, which is an issue seen in many decomposition studies. Although the experiment was designed to maximize the amount of data that could be collected from each individual, a larger number of individuals would provide much needed replication and more independent data observations, which would allow for different types of statistical analyses to be performed. Other types of analysis to be considered would be time series analysis, which possibly could help to explain some of the differences in temperature trends, as opposed to examining the differences on a daily basis.

Another difficult issue to deal with in future projects would be the differences in placement environments of the bodies. Although in this experiment the bodies were all placed close together to limit the amount of environmental variation, the research facility is not a uniform area. As previously noted, some of the bodies were exposed to more consistent sunlight,

the slope of the ground was varied, and even the ambient temperatures were not consistent among each placement. While the magnitude of the effect that this had on the decompositional changes is unknown, ideally all of these factors would be controlled for so as to isolate the specific research variables in question.

A possible expansion of this project would be to carry out this study as a longitudinal experiment, examining decomposition over a much longer period of time. Being able to carry out this experiment until all bodies had completely skeletonized would provide much more detailed information about what effects these coverings have on the entire decomposition process as opposed to just the early stages.

## VI. Conclusion

The bodies of six individuals were placed at the Anthropological Research Facility and subjected to one of three experimental conditions for study. Two bodies were placed on the surface, two were wrapped in cotton thermal blankets, and two were shrouded in plastic tarps. The bodies were allowed to decompose naturally for thirty days while daily temperature measurements were collected and were then uncovered on Day 31 and scored for decomposition. The temperature differences between bodies under different treatments were then compared, as were the accumulated degree days calculated by different methods.

No statistically significant differences were found in temperature between bodies with different coverings, however noticeable differences were observed in decomposition. Covering a body in a cotton thermal blanket appeared to heavily influence the mummification of the body, while encasing a body in a plastic tarp led to moist decomposition and prolonged insect activity, in contrast with the bodies placed on the surface.

Further study is needed to truly determine the effect that various coverings have on decomposition. A larger sample size would be necessary in order to properly evaluate temperature differences statistically, and to ensure that the results are able to be replicated. In addition, other methods of statistical analysis should be examined in order to ensure that overall differences and differences in temperature trends are identified in addition to daily point comparisons. In addition, further research into what constitutes a "significant difference" in temperature in regards to decomposition would be useful to determine if the statistical analyses are evaluating differences on the same scale as the visual assessments.

As this project was by no means a comprehensive study on all the factors that can affect decomposition, further study is also needed to examine the effect of other types of coverings on decomposition, as well as other variables. Decomposition research has expanded significantly since the creation of the Anthropological Research Facility, and will hopefully continue to grow and increase the understanding of the decomposition process.

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## Vita

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