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The Affects of Clothing on Human Decomposition: Implications for Estimating Time Since Death

Robyn Ann Miller
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Robyn Ann Miller entitled "The Affects of Clothing on Human Decomposition: Implications for Estimating Time Since Death." 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.

Murray Marks, Major Professor

We have read this thesis and recommend its acceptance:

Richard Jantz, Walter Klippel

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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THE AFFECTS OF CLOTHING ON HUMAN DECOMPOSITION: IMPLICATIONS FOR ESTIMATING TIME SINCE DEATH

A Thesis

Presented For The

Master of Arts

Degree

The University of Tennessee, Knoxville

Robyn Ann Miller

May 2002

I would like to dedicate this accomplishment to my mother, Patricia Stevens. She has been a continued source of support and encouragement, not to mention a wonderful editor, throughout my academic studies.

And to all the victims of violent crime. May you have peace.

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ABSTRACT

Several studies at the Anthropology Research Facility located at The University of Tennessee, Knoxville, longitudinally examine the process of human decomposition. However, to date, no study has focused exclusively on clothing as a variable in this process. Furthermore, few studies have been performed using animal models. Recent research demonstrates conflicting results regarding the affect of clothing on decomposition. Some authors conclude that clothing accelerates decomposition, while others maintain that it retards the process. The goal of this study is two fold: first, the process of decomposition of clothed human subjects was documented; second, it was determined whether clothing accelerates or retards the process of decomposition. This was accomplished by comparing temperature, i.e., accumulated degree-days, for clothed cadavers with those of nude cadavers.

Over the course of one year, the cadavers of six unembalmed, unautopsied individuals were dressed in clothing and placed at the Anthropology Research Facility to decompose naturally. Subjects were observed and scored on a decomposition staging scale of I to IV. Accumulated degree days were then calculated and compared against values obtained from previous research utilizing nude cadavers. It was determined that clothing retards the process of decomposition in the spring and summer. Clothing was not a significant variable in the winter and no comparison was possible for cadavers used in the fall. This study demonstrates that the presence or absence of clothing must be appreciated and compensated for when making an estimate of time since death.

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I. INTRODUCTION

Forensic anthropology is the branch of physical anthropology that deals with, among other things, the identification of human skeletal remains. Analysis begins with the determination of human versus animal remains. Once remains are identified as human, the forensic anthropologist "undertakes [the process] to provide opinions regarding sex, age, race, stature, and such other characteristics of each individual involved as may lead to his or her recognition" (Stewart 1979: ix). Aside from dealing with skeletal remains, forensic anthropologists are also consulted in soft tissue cases where an individual is unrecognizable, making a visual positive identification impossible due to the advanced state of decomposition. Assessment of skeletal trauma is also often performed. Furthermore, forensic anthropologists are frequently asked to make estimations of time since death (see Bass 1997, Stewart 1979, Snow 1982, Haglund and Sorg 1997, Haglund and Sorg 2001, among others).

Forensic anthropologists are becoming an ever-increasing asset to medical examiners, law enforcement, military and government investigations. In 1897, the first forensic anthropologist testified in a criminal case requiring the identification of skeletal remains (Snow 1982). In 1971, the American Academy of Forensic Sciences formed the physical anthropology section within its organization. Clyde Snow called this "the world's premier organization in the forensic sciences" (Snow 1982:1). By 2000, membership in this section was approximately 250 scholars. This is a large group considering the founding fathers comprised of only fourteen individuals.

The estimation of time since death (TSD) is an enigma that has plagued law enforcement, medical examiners, and forensic anthropologists for years. An accurate estimate is often needed, and may be required for registration purposes by a medical examiner or coroner. In fact, the legal basis of the English coroner's jurisdiction is to "inquire where, when and by what means a person came to his death" (Knight 1995:1). An accurate estimate of time since death is often used in an alibi defense. It can act as a preliminary screening tool to eliminate putative killers who may or may not have had access to the body. More than half of the cases performed by The Forensic Anthropology Center at The University of Tennessee Knoxville require time since death estimates (Marks 1995). Additionally, the success or failure of a criminal investigation may hinge directly upon an accurate estimation of time since death (Marks and Love 2000).

Several methods for elucidating this information for remains in the early postmortem period currently exist. For the first 24 to 48 hours after death, a forensic pathologist can give a reliable estimate of time since death using the ensuing changes of rigor mortis, algor mortis, and livor mortis. Studies have also been performed using vitreous chemistry (James et al. 1997), core body temperature (Nelson 2000), muscular reactivity and enzyme analysis (Knight 1995) to determine time since death within this period. However, the accuracy of estimating this postmortem interval has not kept pace with studies using increasingly sophisticated technology (Knight 1995). The goal in any study of time since death is to produce a valid range of times. It is imperative that caution is taken not to be unreasonably precise as to exclude incorrectly the true time since death.

What about bodies found in more advanced stages of decomposition? Under these circumstances, the aforementioned methods are of not of much use. Since little information on this topic existed, Dr. William M. Bass created the Anthropology Research Facility (ARF) at the University of Tennessee, Knoxville, in 1972. His goal was to create an outdoor research facility where decomposition of the human body could be studied in a natural setting. This facility has proven invaluable. The research conducted at ARF has considerably increased our knowledge of the variables affecting the rate of decomposition (Ubelaker 1996). Studies into the affects of temperature, burial depth, water, and insect activity have been conducted here at length (see Mann et al. 1990, Watkins 1983, Cahoon 1992, Bass 1997, Vass et al. 1992, Haglund and Sorg 1997, 2001, among others).

Variables affecting the rate of decomposition include temperature, body size, the presence of infectious diseases or poisons in the individual prior to death, and insect and carnivore activity. It is well-known that temperature is the most influential factor in the decomposition process (Mann et al. 1990, Bass 1997, Vass et al. 1992). Bodies in warmer weather decompose more quickly than those in cooler conditions. Also, obese bodies decompose more quickly than emaciated individuals (Gonzales et al. 1954, Hewadikaram and Goff 1991). It is also known that the presence of infectious diseases before death accelerates the process of putrefaction due to the increased number and types of bacteria in the body. On the other hand, certain poisons such as arsenic, antimony, zinc, and mercuric chloride tend to preserve soft tissue, thereby inhibiting decomposition (Watkins 1983). Antibiotics, cocaine, or toxemia will also impede putrefaction (Vass 1991). Insects are

responsible for a large amount of tissue destruction, especially in warm tropical environments. However, in temperatures below 0°C, fly eggs and larvae die (Introna et al. 1991). Carnivores and other animals can also affect decomposition by feeding on soft tissue and disarticulating the body (Haglund and Sorg 1997, 2002). All of these factors must be taken into account when making an estimate of time since death.

For years, the prevailing notion was that decomposition was a function of time, and that time since death (TSD), especially in the early stages, could be estimated by taking rectal temperatures of individuals and plugging this information into an algorithm (Lynnerup 1993, Nelson 2000). However, it is now known that the rate of decomposition is not strictly a function of time, but rather of temperature and time. Dr. Arpad Vass (see Vass et al. 1992), a microbiologist from Oak Ridge National Laboratory and adjunct assistant professor of research in the Department of Anthropology at The University of Tennessee, has conducted research at ARF using the breakdown of volatile fatty acids and the concept of accumulated degree days (ADD) initially proposed by Edwards and colleagues (Edwards et al. 1987). Vass discovered that it takes approximately 1285 +/- 110 ADD for a body to demonstrate the initial evidence of skeletonization. Skeletonization, as defined by Vass, is the cessation of volatile fatty acid production. Mummified tissue may still be present on the body in this state (personal communication Vass 2001). ADDs are calculated by taking the average daily temperature and adding them consecutively day to day. Days where the average temperature falls below zero are added in as zero and not a negative number. Vass argues that this method can be used in forensic cases by

taking the average daily temperature at a site for a week, and dividing it into 1285 to arrive at a maximum number of days since death. The closer the body is to skeletonization, the closer the approximate number is to the actual number of days since death. However, after a body has attained skeletonization, the estimation of time since death becomes increasingly difficult.

New methods of determining time since death are under current investigation. Dr. Jennifer C. Love of the Regional Forensic Center in Memphis, Tennessee, has recently completed research into the use of odor (Love 2001). She is developing a "chemical nose" which when passed over a body, will give the approximate time since death. Ms. Jennifer A. Synstelien, a doctoral student at The University of Tennessee Knoxville, is looking at the breakdown of proteins in organs via biopsy samples taken during the first week of decomposition. Her hypothesis is that protein breaks down at a systematic rate and therefore can be used as a marker for estimating time since death.

However, with one exception, no research has been conducted on the affects of clothing on human decomposition and none has been conducted which focuses on clothing as a variable. Cahoon (1992) compared two cadavers, one was clothed and the other nude. Her main focus was to explore the decay of different types of fabric. Furthermore, few animal studies have been conducted on the subject (see Aturaliya and Lukasewycz 1999). Clothing is a highly variable factor in most crime scenes, with the victim's state ranging from nude victims to multiple layers of clothing and wrapping.

Half of all forensic cases consist of clothed individuals, making clothing an important and overlooked variable that has yet to be properly explored (Marks 1995, Bass personal communication 2001). Of the 468 cases examined by Galloway (1997), 57% (n=266) of these had clothing present. Of these 266, 59% were found fully clothed, 19% were partially clothed, and clothing had been removed in 16%. Komar (1998) states that clothing was present in 70% of her forensic cases. Due to these impressive numbers and the variance we might expect, the purpose of this study is to conduct an intensive inquiry into the effects of clothing on the process of decomposition.

Komar (1998) cites a case of an individual missing during the months of January through April in Canada where the mean temperature was -7.1°C. The subject was found wearing only jeans and was completely skeletonized. Extensive carnivore activity was also noted. This unique case brings many variables into the play. Normally, one would not expect a body in this type of environment to be skeletonized in such a short period of time. Did the presence of clothing accelerate the process? Haglund et al. (1989) noted that heavy clothing inhibits scavenger activity and the jeans were still present. What was the role of the temperature? Micozzi (1986) asserts that animals which are frozen and then thawed are disarticulated at a faster rate than fresh killed animals due to the damage to tissue by freezing. What role did this process play in this case? All of these factors have coincidentally presented themselves during the course of this study and are discussed in further depth in the discussion section of this study.

II. EARLY POSTMORTEM EVENTS

Early postmortem changes are observable by the pathologist through the processes of rigor mortis, algor mortis, and livor mortis. These are first observed approximately two to four hours after death (Gonzales et al. 1954). Rigor mortis is the stiffening and release of the muscles. Rigor typically presents during the first three hours after death and is fully developed after approximately 10-12 hours. It remains for 24 to 36 hours, on average, and then dissipates (Dix and Graham 2000). This phenomenon is a result of the change in pH status in muscle protoplasm. Conversion of glycogen to sarcolactic and phosphoric acids converts the pH level from alkaline to acid, resulting in a stiffening of the muscles (Gonzales 1954). This stiffening remains for 12 to 36 hours and ceases when the muscle protoplasm becomes alkaline again. Rigor mortis is accelerated by heat. If an individual is suffering from a fever or heavy physical exertion prior to death, rigor will present much earlier than in bodies with a normal temperature at death (Clark et al. 1997). Pathologists have traditionally "diagnosed" rigor as a rough means of estimating time since death.

Livor mortis is the phenomenon of postmortem blood pooling. Due to circulatory stasis, soon after death gravity begins to gradually take affect on blood in the body. This results in pooling of blood in the capillary beds of dependent regions of the body (Perper 1993). It is noticeable within about an hour postmortem and is fixed within 8 to12 hours. At this point, if the body is moved, "staining" or "blanching" will remain intact at contact areas rather than move to a new area.

Algor mortis is the process of body cooling. After death, body temperature declines until ambient temperature is attained. Approximately 1.5°F to 2.0°F per hour is lost during the first twelve hours postmortem. The rate then slows to approximately 1.0°F per hour until the body reaches ambient temperature (Perper 1993). Bodies with more fat or heavy clothing may cool at a slower rate. Knight discovered that a 76 kilogram body, when clothed, cooled at a rate expected of a 109 kilogram body (Knight 1995).

AUTOLYSIS AND PUTREFACTION

Destruction of body tissue occurs through the processes of autolysis, putrefaction, and decay. Putrefaction is the anaerobic degradation of body tissue, while decay is aerobic (Micozzi 1991). The early stages of putrefaction begin with autolysis. Autolysis is the process of cell death by intra and extracellular enzymes. Depletion of oxygen in the blood triggers a decrease in intracellular pH. As a result, hydrolytic enzymes begin to digest carbohydrates and proteins. Because the cell membrane has collapsed, these molecules are released into the bloodstream where microorganisms proceed to feed upon them (Clark et al. 1997). Bacteria use these protein and carbohydrate molecules as culture media and flourish. These organisms gain access to blood, lymph and tissue from the intestines (Evans 1963). As a result, a green discoloration of the abdominal region is apparent beginning anywhere from 24 to 48 hours postmortem. This discoloration is the product of sulfmethemoglobin and iron sulfide in nearby tissues. Together, they create hydrogen sulfide in the large intestine (Gonzales 1954). Externally, skin slippage is apparent. This epidermal

sloughing is caused by the postmortem release of hydrolytic enzymes at the epidermal-dermal junction of the skin. As a result, the epidermis loosens and skin begins to literally "slip" off. Hair and nails also become loose and eventually glide off (Clark et al. 1997).

Aerobic organisms deplete the body of oxygen, leaving anaerobic organisms to take over the job. Sugars are formed from glycogen, and further destruction of the body proceeds by way of lactic acid to produce large amounts of carbon dioxide and water (Evans 1963). Gas forming bacteria invade the stomach, intestinal walls and blood vessels. Hemolysis occurs in the blood vessels and blood that is not destroyed is forced to the periphery by gas bubbles (Gonzales et al. 1954). Visualization of this blood is apparent on the surface of the skin. Additional vascular discoloration, referred to as infravascular hemolysis, marbling or suggillation, is caused by oxidation of bile pigments and precipitates of hydrogen sulfide (Gill-King 1997). As gas pressure within the body rises, tissues are distorted. The eyes begin to bulge, blisters or bullae form on the skin and burst, and the entire body increases in size (Marks and Love 2000). Eventually, these gases are released either through the orifices, through tissue ruptured by gaseous pressure, or by carnivores. After the gases dissipate the abdominal cavity caves in and the internal organs begin to liquefy.

VARIABLES IN THE PROCESS OF DECOMPOSITION

Essentially, all mammalian bodies go through the same processes, but temperature will dictate the velocity and overall time spent in each stage (Gill-King

1997). Van't Hoff's rule states "the velocity of chemical reactions increases two or more times with each 10°C rise in temperature" (Gill-King 1997:93). The above processes may be slowed or even halted if the body is in an extremely cold climate or refrigerated. Micozzi observed that animals which were frozen and then thawed experienced prominent decay (from the outside in), whereas unfrozen animals experience mainly putrefaction (from the inside out) (Micozzi 1991, 1997). He states "no putrefaction occurs at temperatures less than 4°C" (Micozzi 1991:37). In temperatures below 12°C, bacterial reproduction is severely retarded. Elevated temperatures alternately accelerate decomposition. Temperatures between 15 and 37°C provide a favorable environment for increased bacterial action (Micozzi 1997). Bodies in warm, moist climates decompose more rapidly due to the favorable conditions for the growth of putrefactive bacteria (Gonzales et al. 1954). Bass (1997) has observed that a body in a hot humid climate may take as little as two weeks to completely skeletonize. As temperatures reach 40°C, the time required for bacterial cell division approaches infinity (Micozzi 1991). In other words, bacterial cell reproduction becomes invirtually nonexistent. Individuals who are suffering from infectious diseases prior to death may putrefy more rapidly, as will obese individuals (Polson 1996). Hewadikaran and colleagues (1991) conducted a study on the effect of carcass size on the rate of decomposition and discovered that a 15.1 kilogram (kg) pig carcass decomposed more quickly than one weighing 8.4 kgs. Gonzales points out that this excess fat slows the dissipation of body heat. The excess of body fluid also furnishes beneficial conditions for bacterial growth. The

presence of certain poisons in the blood stream, such as arsenic, antimony, zinc, mercuric chloride, cocaine, antibiotics and lead can retard the decomposition process (Watkins 1983, Vass 1991). Alternately, external wounds accelerate the process, providing additional points of entry for bacteria and parasites (Gonzales et al. 1954).

The processes of putrefaction and decay are capable of completely skeletonizing a body. However, other factors such as insect activity and carnivore disturbances are usually present and work to accelerate the process (see Haglund and Sorg 1997). Mummification and adipocere formation are two processes by which preservation of the body occurs rather than skeletonization. Mummification typically transpires in dry humid environments, but can also occur in extreme cold (Clark et al. 1997). Galloway (1997) notes that increased temperatures coupled with decreased humidity can result in surface dehydration and mummification in as little as two weeks. Adipocere, a grayish-white, soapy substance also referred to as "grave wax," typically forms on bodies submerged in water, buried for extended periods in cool moist environments, and may also occur on bodies in plastic bags. It has also been observed in dry environments (Mellen et al. 1993). This cheesy compound forms via the hydrolysis and hydrogenation of fats to fatty acids (Clark et al. 1997, Evans 1963, Gill-King 1997). It requires some form of water, either from the external environment or from the body itself. Adipocere formation seems to be more common in female corpses due to the greater fat content of the body (Micozzi 1991) and is accelerated by the presence of clothing (Mellen et al. 1993).

INSECT ACTIVITY

Insect activity, as well carnivore and animal damage, hastens the decomposition process (Gonzales 1954). Bass (1997) states that the primary process accelerating decomposition is insect activity. It has been said, "three flies would destroy a horse carcass as fast as a lion would" (Campobasso et al. 2001, p.3 online at www.sciencedirect.com). Blowflies will be attracted to a body within minutes of its deposition in a field. Necrophagous arthropods, like Calliphoridae (which includes blowflies), have special receptors stimulated by the putrefactive gases (Campobasso et al. 2001). Blowflies typically lay eggs around the eyes, nostrils, mouth, ears, genitals, and at the shaded ground-body interface. They prefer warm, protected areas away from direct sunlight (Byrd and Castner 2000). In 8 to 14 hours, these eggs hatch into larvae (maggots), which begin to feed and burrow into soft tissue. These insect larvae cause focal liquefaction of the body via proteolysis (the decomposition of protein) (Evans 1963). Maggots typically hatch in large groups and move around the corpse together. Through enzyme secretion and bacterial dissemination, they are able to consume nearly all of the soft tissue (Lord 1990). Cockroaches, ants, bees, and beetles also feed on the corpse. Ants typically feed on the epidermis, which allows the dermis beneath to dry. Necrophagous insects, repelled by the more active phases of decomposition, reappear in subsequent phases (Evans 1963). Insects can be responsible for displacement of skeletal elements and clothing. Komar and Beattie (1998) observed that maggot masses and other insect activity could produce changes that mimic sexual assault. They observed maggot masses shift clothing positions in a matter of minutes. Furthermore, clothing

arrangements changed daily from the initial appearance of maggots to the time when they were no longer observed.

Insects, like other contributors to the process of bodily destruction, are subject to variation in temperature. Oviposition is generally not observed during strong wind, rain, or during the night (Introna et al. 1991). Eggs will die if exposed to temperatures below 0°C and temperatures below 10°C tend to inhibit insect activity (Haskell 1997). The larval stage is directly correlated with ambient temperature. Anything below 10°C delays development and wide fluctuations in day and night temperatures can be lethal to certain larvae (Introna et al. 1991). However, well-developed larvae situated in a large group, as well as eggs laid in sheltered areas are protected against wide fluctuations in temperature (Campobasso et al. 2001). The abundance and types of insects active on a cadaver vary seasonally. The warmer temperatures of spring and summer are more favorable to insect activity. Therefore, insects will be more abundant and a greater variety of species will be active. However, cooler temperatures deter insect fauna, limiting the type of species and number of insects frequenting the body (Campobasso et al. 2001).

Insect families known to visit decomposing bodies in East Tennessee include Calliphoridae (blow fly), Muscidae (muscid fly), Silphidae (carrion beetle), Sarcophagidae (flesh fly), Histeridae (clown beetle), Staphylinidae (rove beetle), Nitidulidae (sap beetle), Cleridae (checkered beetle), Dermestidae (dermestid beetle), and Scarabaeidae (lamellicorn beetle) (Rodriguez and Bass 1983).

CLOTHING

The focus of this study is to assess the effects of clothing on the process of decomposition. Current literature exhibits contrasting views as to the observed affects of clothing. Several authors have concluded that the presence of clothing retards the decomposition process. Gonzales and colleagues (1954) note that clothed cadavers decompose at a slower rate than those which are nude. They theorize that the pressure of the clothing prevents full enlargement of body tissues (bloating) and restricts the movement of organisms through the blood. Galloway and colleagues (1989) concur with this theory. They discovered that when clothing covered the bodies, decomposition was retarded especially in the advanced stages. Haglund (1989) states that heavy clothing inhibits scavenger activity, which may lead to a decrease in the rate of decomposition.

However, other authors have come to different conclusions. Cahoon (1992) observed decomposition in one nude and one clothed cadaver. She noticed that the clothed cadaver decomposed more quickly than the nude one in winter. In fact, she reports that the clothed cadaver reached the bloating stage almost twice as fast as the nude cadaver. She hypothesized that this acceleration was due to the facilitated growth and development of insects. Aturaliya and Lukasewycz (1999) conducted an experiment using mice and rats, where clothed versus nude animals were compared. Two mice were shaved and placed in an environmental chamber, which pumped 785 mL/min of 22°C dry air. One remained nude while the other was wrapped in cloth to simulate the presence of clothing. After 69 days, the "clothed" mouse had lost 71.3% of its body weight and the nude mouse had lost only 58.6%. This experiment

was repeated using rats (which are larger animals) and obtained similar results (65.3% versus 51.2%). These results led them to conclude that clothing accelerates the rate of desiccation. This implies that decompositional rate would also be increased. Furthermore, Mann and colleagues (1990) observed that decomposition was accelerated by the presence of clothing. They hypothesize that clothing shelters the body from sunlight, giving maggots a place to remain active in darkness. This in turn accelerates the decomposition process. An experiment in body cooling in the early postmortem period is described by Knight (1995). He observed that a 76 kg body, when clothed, cooled at a rate expected of a 109 kg body. After removing the clothing, the body cooled at a rate expected of a 72 kg body. Obviously, there is a discrepancy here. Granted, this experiment was in the early postmortem period. However, this gives insight to the fact that clothing does have a significant affect in body cooling, and therefore may have an affect on the rate of decomposition. Campobasso and colleagues (2001) state that clothing, while providing protection for larvae, can impede insect access to decomposing tissue. The resultant decrease in insect activity would slow the rate of decomposition. Clothing has been mentioned only as a variable in passing by several other authors (Rodriguez and Bass 1985, Willey and Snyder 1989, Komar 1998).

III. MATERIALS AND METHODS

The venue for this study is the Anthropology Research Facility (ARF). ARF is a fenced, open-wooded one acre lot situated adjacent to The University of Tennessee Medical Center in Knoxville, TN (see figure 1). ARF has a self-contained weather station, which records climatological data. High and low temperatures are recorded at this weather station for a single twenty-four hour period. These data were recorded from the station each month for three days. Daily temperatures were recorded from the National Weather Service (NWS). The NWS weather station is located at the Tyson-McGhee Airport, approximately 16 km from ARF. Average temperatures were calculated for three days once month at ARF and compared to the information received by the NWS. A calibration estimate was then calculated by taking the differences in temperature between ARF and the NWS station. On average, temperature at ARF deviated one to two degrees from the temperatures reported by the National Weather Service. Average daily temperature readings were calculated and accumulated degree days (ADD) were computed using this data for each subject. As outlined by Vass (1991), ADDs are calculated by adding the daily average temperature of each day consecutively, beginning with zero for the first day. Any day that the average temperature falls below zero centigrade is counted as zero, and not added in as a negative number. Vass determined that it takes approximately 1285 +/- 110 accumulated degree-days for volatile fatty acid production to cease and the body to reach the initial stages of skeletonization.

Figure 1: The Anthropology Research Facility

The cadavers of six unembalmed, unautopsied adult humans were used in this study: four white males, one white female, and one black male. All cadavers were of normal body composition for their height and were donated to The University of Tennessee, Department of Anthropology for scientific research purposes. Upon arrival, information concerning height, weight, age, sex, ancestry, date and cause of death was recorded for each individual and entered into the William M. Bass Donated Skeletal Collection database. Each body was photographed before being dressed. Subjects used in cooler months were outfitted in a t-shirt, sweatpants and a sweatshirt. Subjects used in warmer months were outfitted in a t-shirt and sweatpants only. This variation was done in order to mimic actual clothing that might be found on a decedent, correlating with the time of year. Each was then placed in a supine position. At every observation session, body decomposition, carnivore, and insect activity were noted. During the warmer spring and summer months, observations were made daily. In the cooler months of the fall and winter, observations were made daily, or every few day due to the slowed nature of decomposition. Photographs were taken as observations noted considerable change. Specimens were assigned a score of 1 to 4 on a modified decomposition staging (see table 1 for scale used in this study) scale outlined by Reed (1958) and Galloway et al. (1989) (see table 2 for Galloway et al. 1989 staging scale). These scores correspond with the stages of (I) fresh, (II) early decomposition, (III) advanced decomposition, and (IV) skeletonization.

Table 1: Decomposition Staging Scale

Stage I: Fresh

- No insect activity
- No discoloration, except for lividity

Stage II: Early Decomposition

- Green discoloration of abdomen and marbling of extremities
- Bloating of all body parts, from initial boating until maximum bloating or size is attained
- Beginning of skin slippage on hands, arms, legs and feet
- Extensive maggot activity
- Extensive insect activity, including flies, bees, some species of beetles, ants and cockroaches

Stage III: Advanced Decomposition

- Caving in of thoracic and abdominal cavities due to the dissipation of gases, either through rupture of tissue, body orifices or carnivore activity
- Extensive maggot activity
- Further destruction of soft tissue through autolysis and insect and carnivore activity
- Skin slippage and hair loss

Stage IV: Skeletonization

- Dry bones
- Bones containing desiccated and mummified tissue
- Various species of beetles present
- Bleached and exfoliated bones (late stage)

Table 2: Decomposition Staging Scale from Galloway et al. 1989

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.

The fresh stage (stage I) is marked by the absence of discoloration, except for lividity, and the absence of maggot activity. This stage begins immediately after death and ends with the first signs of early decomposition.

The early decomposition stage (stage II) consists of the green discoloration of the abdomen as well as marbling, bloating of all body parts until maximum bloating (or size) has been attained, and skin slippage on all extremities. Hair and nails may slide off in stage II or stage III. In addition, maggot masses are active and a large amount of insect activity, including blowflies, bees, certain species of beetle, and ants is observed.

The advanced decomposition stage begins with the collapse of the thoracic and abdominal cavities. This is a result of gas dissipation, either through the rupture of tissue by gaseous pressure, through body orifices, or from carnivore activity. Extensive maggot activity is observed during this stage. Skin slippage may still be in process, and exposed dermis will be slick and greasy in appearance. Discoloration of the body is extensive and the body may be very dark in color, regardless of ancestry. Bodies remain in this stage throughout the final destruction of soft tissue.

The beginning of the skeletonization stage (stage IV) is marked by dry remains and includes mummified tissue. Bones may be dry or contain desiccated and mummified tissue. No maggots are observed at this stage, though various species of beetles and small gnats remain active. The end stages of skeletonization (not observed in this study) include exfoliated and bleached bones.

Obviously patterns of decomposition are more discernible in the warmer months of summer. Extensive freezing and lack of decay organisms in winter

"preclude observations of definitive decay patterns during this season" (Micozzi 1991:43). Carnivores and other animals are also more aggressive in winter months, due to limited food resources, altering definitive stages of decomposition (Bass 1997).

IV. RESULTS

This chapter discusses the progression of events of each cadaver and the respective accumulated degree-days required for each body to attain stages 1-IV. Criteria for identifying each stage are listed in Table 1.

Insect and/or animal activity was observed on all bodies. Vultures have been observed plucking out the eyes of cadavers (see figure 2), and raccoons have also been observed to consume a large quantity of soft tissue at the facility. A small animal, which was determined to be a short tail shrew (*Blarina brevicanda*) repeatedly burrowed under the rocks surrounding the cage where #4-01 was placed. It chewed away small portions of flesh, focusing on the facial region.

SUBJECT #4-01

Subject #4-01 is an elderly white male. Upon arrival, he was outfitted in a t-shirt, sweatpants and a sweatshirt (see table 3 for observations and ADDs). He was positioned at the Anthropology Research Facility (ARF) in a wire-mesh cage on 12 January 2001. Photographs were taken upon arrival and after clothing was placed on the body (see Figures 3-7). Initial observations included a green discoloration to the abdomen accompanied by swelling and the beginning stages of skin slippage. On day 14 (accumulated degree day 47.4), the body showed signs of bloating, marbling in the extremities, and damage to the face. This damage was made by a short tailed shrew which burrowed under the cage.

The cold weather inhibited any insect activity and severely retarded the process of putrefaction. By day 56 (ADD 392), there was a noticeable darkening of

Figure 2: A vulture visiting #8-01

Table 3: Results for #4-01

Date	ADD	Stage	Observations
1/12/2001	0	2	Slight green discoloration in abdomen accompanied by swelling, beginning skin slippage apparent in hands and feet.
1/17/2001	21.65	2	Shrew has chewed on the right side of the mouth.
1/26/2001	47.4	2	Body is showing signs of bloating, marbling apparent in extremities, more rodent damage to face.
2/5/2001	92.2	2	Mouth region entirely gone due to shrew activity.
2/20/2001	219	2	Feet almost entirely green, abdomen and thighs showing more bloating
3/9/2001	392	2	Overall darkening of all exposed areas
3/14/2001	439.1	2	A large number of blowflies in cage. Considerable darkening of extremities, more bloating and underside of body is wet.
4/5/2001	660.7	2	Markedly more bloating, heavy fly activity, no maggots visible.
4/12/2001	817.1	2	An extremely large amount of maggot activity, they have dragged pants down and are on abdomen and right side of body.
4/15/2001	876.8	3	Stomach caving in, liquid flesh pouring out. Genitals exposed, maggots everywhere.
4/23/2001	993.2	3	Body almost skeletonized, tons of small insects everywhere.
4/25/2001	1031.9	4	Hands and feet are desiccated, some desiccated tissue on abdomen and pelvis.
6/10/2001	2012.1	4	Skin on feet are turning white, further destruction of tissue on face.

Figure 3: #4-01 on 1/13/2001. Stage I: Fresh

Figure 4: #4-01 on 3/5/2001. Stage II - Shrew damage to the face and hands, and bloating is apparent.

Figure 5: #4-01 on 4/2/2001 Stage II – feet are discolored and fluids are being released

Figure 6: #4-01 on 4/20/2001. Stage III – Bloating has dissipated and pubis is visible. The face exhibits extensive shrew damage.

Figure 7: #4-01 on 5/14/2001. Stage IV – Desiccated tissue remains on some limbs and the face while the pelvis is dry bone.

all exposed areas and by accumulated degree-day 439.31, things had begun to make noticeable progress. A large mass of blowflies was observed in the cage, and a considerable darkening of all exposed areas was noted as was a great deal of bloating. Additionally, the underside of the body was wet. On 12 April, a large mass of maggots was active and had moved the pants distally down the abdomen. #4-01 reached stage III on 15 April after 876.8 accumulated degree days. On this day, observations included a large mass of maggots in the thoracic region, a concave appearance of the abdomen, and putty-like putrefied flesh pouring out from the body.

Stage IV was reached on 25 April after 1031.9 accumulated degree days. The hands and feet had become desiccated, as had tissue on the abdomen and pelvis. In total, this body was exposed for 215 days. It took 1031.9 accumulated degree-days for this body to reach stage IV.

SUBJECT 8-01

Subject #8-01 is a 60 to 70 year-old white male. He was outfitted in a t-shirt, sweatpants and sweatshirt and placed uncaged at ARF on 24 January 2001 (see table 4 for observations and ADDs). Photographs were taken before and after clothing was placed on the body (see figures 8-13). At placement, there was an absence of trauma and any discoloration, except for fixed lividity.

After the fourth day (ADD 4.85), marbling was apparent in the extremities and the face showed slight discoloration. On accumulated degree-day 17.15, subject #8-01 exhibited signs of bloating and a flaking of the epidermis on both hands. On day 12 (ADD 49.7), discoloration of the abdomen and bloating was observed. On

Table 4: Results for #8-01

Date	ADD	Stage	Observations
1/24/2001	0	1	No rigor, livor is fixed, no discoloration. Body was outfitted in T-shirt, sweatpants and sweatshirt.
1/28/2001	4.85	1	Marbling apparent in extremities, face shows slight discoloration.
1/30/2001	17.15	2	Signs of bloating, slight flaking of the epidermis on hands.
2/6/2001	49.7	2	Putrid smell, discoloration of abdomen apparent, bloating present.
2/11/2001	92.45	2	Right side of face is sagging, insect marks on right leg, significantly more
2/22/2001	193.9	2	Marbling and overall darkening of all exposed surfaces. Fly activity present but no eggs or maggots observed.
			Solid bloat throughout body with slippage of epidermis on all exposed surfaces.
3/4/2001	313.65	2	Moderate ant activity observed, although no maggots observed.
			More carnivore activity to left leg. It has been hollowed out.
3/30/2001	542.9	2	Mold/algae growing on left side of neck and only one blowfly observed.
4/8/2001	677.7	2	Heavy insect activity, especially in right eye and underside of right portion of abdomen. Right leg is moist.
4/29/2001	1057.1	2	More bloating and heavy insect activity. Animal activity noted on right hand and foot.
5/15/2001	1388.9	3	Substantial foam around head. Fluids are being released from midsection.
5/21/2001	1539.8	3	Stomach has decreased to the point where innominates are visible. Large area around torso is wet.
6/5/2001	1842.7	3	Further destruction of soft tissue. Skin on face is desiccated and facial bones visible.
6/10/2001	1966.7	4	Skull entirely visible. Skin on abdomen is desiccated.

Figure 8: #8-01 on 1/24/2001. Stage I: Fresh

Figure 9: #8-01 on 2/28/2001. Stage II – vultures have plucked out the eyes and picked at the flesh on the face.

Figure 10: #8-01 on 3/27/2001. Stage II – note the animal damage to the left leg and bloating.

Figure 11: #8-01 on 4/25/2001. Stage II – the exposed are of the abdomen has dried and mold has formed.

Figure 12: #8-01 on 5/18/2001. Stage III – notice the removal of tissue from the legs by carnivores and the dissipation of bloating.

Figure 13: #8-01 on 6/7/2001. Stage IV – in figure 12, fluids were being purged but the abdomen remained intact. Notice here how the abdominal tissue is no longer intact and the pelvis is exposed.

February 22 (ADD 193.9), marbling and an overall darkening of exposed areas was observed. Fly activity was present though no maggots were observed. Furthermore, bloating was visible throughout the entire body and skin slippage was noticed on all exposed areas. #8-01 remained in stage II for 90 days during which time animal activity on the legs and hands had occurred. Vultures were also witnessed plucking out the eyes.

Stage III was attained on 15 May 2001, 111 days after placement and accumulated degree-day 1388.9. Observations made on this day include a substantial amount of a foamy substance, a by-product of maggot feeding, around the head and neck region, and the release of fluids around the midsection. Bloating had also decreased. The abdominal cavity had caved in to the point were the innominates were visible by accumulated degree-day 1539.8. Moreover, a large area around the torso was very wet.

Subject #8-01 reached stage IV on 10 June 2001 after 1966.7 accumulated degree-days and on day 137 of tenure at the facility. Observations on this day included desiccated skin on the abdomen and a nearly clean skull.

#8-01 was removed from the facility on 31 October 2001. First the clothing was removed. Skin on the arms and legs had adhered to the clothing and was peeled away. The patellar ligament was firmly attached to the patella and was left intact. The thoracic cavity revealed a large number of worms and a small amount of moist putrefied tissue mass. The pelvic region also contained moist tissue mass and excrement was pulled away from the left innominate. Furthermore, both scapulae

were adhered to the clothing. All skeletal elements were recovered and brought to the morgue for processing.

SUBJECT #10-01

#10-01 is a white female in her mid seventies. She was clothed and placed uncaged at ARF on 29 January 2001 (see table 5 for observations and ADDs). Upon arrival, she was photographed before and after clothing placement (see figures 14-19). She was outfitted in a t-shirt, sweatpants and a sweatshirt. Observations include slight rigor in arms and fixed lividity. Furthermore, a surgical site was noted on the inside of the right leg extending from the upper thigh to just below the calf. Removal of the great saphenous vein for coronary bypass surgery is the most likely explanation for this wound, although records merely indicated "heart surgery."

Animal activity was noted on the body early on. A short tail shrew and vultures have been observed. By day 3 (ADD 30.25) the left ear and lips had been chewed off and the left forearm was defleshed down to the bone. Furthermore, the legs showed some signs of discoloration. On 11 February (ADD 84.95), bloating was present in the abdomen, upper thighs and neck. Further animal damage was noted to the left arm, and a peak under the clothing revealed that this damage extended up to the elbow, even though this area was clothed. Observations on accumulated degree-day 670.2 included a significant increase in bloating, a large amount of insects on and around the body, a large number of maggots on various

Table 5: Results for #10-01

Date	ADD	Stage	Observations
1/29/2001	0	1	Body arrived today with slight rigor in arms and fixed lividity. Subject was outfitted in a T-shirt, sweatshirt and sweatpants.
2/1/2001	30.25	2	Left ear and lips have been chewed off, left forearm down to bone due to animal activity, legs showing some discoloration
2/11/2001	84.95	2	Bloating present in abdomen, upper thighs, and neck. Lifting of sleeve reveals animal damage on arm extends to left elbow even though this area was covered.
3/27/2001	513.6	2	Heavy fly activity. Head has a greasy appearance, lips gone and dentition visible. Neck is black nose is almost absent and face skin is slipping to right side of face.
4/8/2001	670.2	2	Significantly more bloating. Body is completely wet except abdomen. Heavy insect and maggot activity. More slippage off of right foot.
4/16/2001	844.9	3	Bloating decreasing, liquefied tissue surrounding entire body.
4/25/2001	981.2	3	Heavy insect activity, further caving of abdomen, maggots in abdominal region, more leaching of fluids.
5/24/2001	1593.6	3	Appears that stomach is nearly entirely flattened. Outline of vertebral column is visible through skin and clothing.
5/31/2001	1730.6	4	Pelvis and spine are visible, as are legs through clothing.

Figure 14: #10-01 on 1/29/2001. Stage I: Fresh

Figure 15: #10-01 on 2/19/2001. Stage II – vultures have plucked out the eyes and consumed the nose and lips.

Figure 16: #10-01 on 3/27/2001. Stage II – notice the fluids around the feet, animal damage to the face and arms, and bloating in the abdominal region.

Figure 17: #10-01 on 4/6/2001. Stage II – fluids are being released in the lower extremities.

Figure 18: #10-01 on 4/20/2001. Stage III – notice the substantial purging of fluids and the sagging abdominal cavity.

Figure 19: #10-01 on 5/24/2001. Stage IV – dried tissue remains on the body.

parts of the body, skin slippage on the right foot, and the body was completely wet except for the abdomen.

Subject #10-01 reached stage III on 16 April (ADD 844.9), after 77 days of exposure. On this date, bloating had decreased and liquefied tissue surrounded the entire body. Observations on 24 May (ADD 1593.6) revealed a nearly entirely flattened abdomen, visibility of the vertebral column (although covered by skin and clothing), and further destruction of surrounding tissue. On 31 May, #10-01 reached stage IV. She had been at the facility for 122 days and 1730.6 accumulated degree-days.

SUBJECT 23-01

#23-01 is an 80 year-old white male. He was placed uncaged at ARF on 6 June 2001 after being outfitted in a t-shirt and sweatpants (see table 6 for observations and ADDs). Photographs were taken before and after clothing placement (see figures 20-25). Another student placed this subject at ARF in the morning, and I was unable to attend to the body until the afternoon. Upon my arrival at the facility, an egg mass had already been deposited in the right eye. The belly was soft and distended with no discoloration.

By the next day (ADD 26.6), bloating was apparent and a large mass of blowflies was observed swarming the body. Day 6 (ADD 146.2) revealed extreme bloating, a large maggot mass, a flurry of insect activity, and skin had sloughed off

Table 6: Results for #23-01

Date	ADD	Stage	Observations
6/6/2001	0	1	No rigor, fixed lividity on butt and thighs, egg mass in right eye. Belly is soft and distended with no discoloration.
			Feet are unkempt. I dressed the body in a T-shirt and sweatpants.
6/7/2001	26.6	2	Heavy fly activity, especially around face. Bloating apparent.
6/12/2001	146.2	2	Genitals enlarged and visible through pants, body is moist and skin has sloughed off arms and left foot. Face has 'dripped' to the left.
			Heavy insect and maggot activity. Belly extremely bloated.
6/15/2001	224.4	3	Bloating has decreased, heavy maggot activity, light insect activity, and maggots visible in genital area.
6/21/2001	383.9	3	Abdomen has caved in. Epidermis has slipped off all extremities. Lots of gnats. Burrow marks on arms and a few maggots are visible.
7/18/2001	1072.2	4	Skin on abdomen and face is leathery and desiccated. Exposed arms and legs are also dry.

Figure 20: #23-01 on 6/6/2001. Stage I: Fresh

Figure 21: #23-01 on 6/7/2001. Stage II – notice the egg masses in the eyes and nose and the large number of blowflies on the face.

Figure 22: #23-01 on 6/12/2001. Stage II: the body is extremely bloated, maggots are visible throughout the body, skin has slipped off of the arms and hands, the face is unrecognizable

Figure 23: #23-01 on 6/15/2001. Stage III – drying putrefied flesh is visible surrounding the head, and the skin is discolored.

Figure 24: #23-01 on 6/18/2001. Stage III – the abdomen has caved in and fluids are being released. Note the maggots dispersed throughout the body.

Figure 25: #23-01 on 9/5/2001 after clothing was cut open. The skin is mummified and dry bones are visible.

of the arms and feet. Decomposition on the face revealed the affects of gravity. Tissue has begun to slide from the right to the left, in the direction the head was turned. #23-01 reached stage III at 224.4 accumulated degree days, nine days after placement at the facility. On this day, observations included a dissipation of bloating compared to previous days, a large amount of maggots active throughout the body, and a small number of insects on and around the body.

By accumulated degree-day 383.9, the abdomen had caved in and the epidermis had slipped off of all exposed areas. Lots of gnats were observed, as were burrow marks on the arms. Subject #23-01 reached stage IV on 18 July after 1072.2 accumulated degree-days and 42 days after placement at the facility. At this point, all exposed areas were dry and desiccated.

SUBJECT #30-01

#30-01 is 60-70 year-old black male who was placed in a cage at ARF on 5 September 2001 (see table 7 for observations and ADDs). He was outfitted in a t-shirt and sweatpants. Photographs were taken before and after clothing placement (see figures 26-31). Initial observations included moist skin, fixed lividity, and an IV access site in the right antecubital fossa. A bandage covered the wound and no other trauma was observed.

Stage II was reached the following day. Blowflies were observed on the face and in the mouth, and oviposition was noted in the mouth and eyes. Furthermore, ants or cockroaches have removed skin on the left metacarpals and a few yellow

Table 7: Results for #30-01

Date	ADD	Stage	Observations
9/5/2001	0	1	Rigor released, fixed lividity, subject has been in cooler for approx. one week. Skin is moist as body is thawing. No trauma, iv access site in right elbow.
9/6/2001	25	2	Blowflies on face and in mouth. Oviposition noted in mouth and eyes, ants have consumed skin on left metacarpals, yellow jackets present.
9/9/2001	100.5	2	Body has bloated to approximately 2.5 times normal size, maggots cover entire head and are visible through chest & arm clothing, face is disfigured, blowflies and yellowjackets present. Skin has slipped off of arms and hands, skin is slick & moist, part of lower legs are exposed
9/11/2001	148.9	3	Face has been defleshed and intestines are exposed. Heavy maggot activity on abdomen, shirt raised and maggots on legs
9/15/2001	238.4	3	Deflation of entire body, further destruction of abdomen and entire body, no maggot or insect activity noted today.
9/18/2001	293.4	3	Abdomen has continued to sink in, heavy insect activity, mostly gnats, flying ants and some blowflies, further destruction of body apparent.
9/25/2001	431.7	3	Further destruction of abdomen, skin on face is leathery and hard, left thigh still thick with flesh, skin on extremities is becoming leathery, innominates are visible
10/5/2001	581.2	3	Lots of insect activity, soft tissue still palpable under pants, further desiccation of skin
10/30/2001	923.9	4	No palpable tissue, more drying, no insect activity.

Figure 26: #30-01 on 9/5/2001. Stage I: Fresh

Figure 27: #30-01 on 9/9/2001. Stage II – extensive maggot activity, bloating and skin slippage on extremities.

Figure 28: #30-01 on 9/11/2001. Stage III – the abdominal cavity has burst, exposing intestines. Note the extensive maggot activity all over the body.

Figure 29: #30-01 on 9/13/2001. Stage III – notice the skeletonized facial region.

Figure 30: #30-01 on 10/5/2001 Stage III – the exposed tissue is drying.

Figure 31: #30-01 on 10/30/2001. Stage IV – desiccated skin remains on the face and limbs, though the facial region shows some dry bone.

jackets were observed around the body. By day 4 (ADD 100.5), the body had bloated to approximately four times its normal size. Maggots covered the entire head and were visible through the clothing on the thoracic cavity and arms. A large mass of blowflies and yellow jackets were observed and the epidermis had slipped off of the arms and hands. The remaining skin was slick and moist and part of the lower legs had been exposed due to bloating.

On day 6 (ADD 148.9), #30-01 reached stage III. The abdominal cavity had burst, exposing the intestines. Furthermore, a large mass of maggots on the abdomen and on legs was visible. The facial region had been defleshed, and the shirt had been raised on the abdomen. Deflation of the entire body and an absence of insect and maggot activity were observed on ADD 238.4. On ADD 431.7, further destruction of the abdomen was noted. Skin on the face was leathery and hard, and skin on the extremities was becoming leathery as well. The innominates were visible, but the left thigh was still thick with flesh. On 30 October (ADD 923.9), no palpable tissue was present and the skin was dry and hard. Furthermore, no insect activity was observed on this day. #30-01 reached stage IV on this day after 55 days of exposure.

SUBJECT #31-01

#31-01 is a white male in his mid-seventies who was placed uncaged at ARF on 15 September 2001 (see table 8 for observations and ADDs). He was outfitted in a t-shirt and sweatpants. Photographs were taken before and after clothing placement (see figures 32-37). Initial observations included an absence of trauma,

Table 8: Results for #31-01

Date	ADD	Stage	Observations
9/15/2001	0	1	Placed subject in t-shirt and sweatpants uncaged at ARF. Observed many flies and yellowjackets swarming body. Body has no evidence of trauma, slight mold visible on left upper thigh.
9/16/2001	18.9	2	Blowflies and yellowjackets swarming the body, some oviposition noted in mouth and ant activity on right arm.
9/18/2001	55	2	Freshly hatched maggot mass in nose and ear, more ant activity on chest and right arm.
9/21/2001	113.9	2	More marked bloating, skin slippage on both arms, discoloration of feet
9/25/2001	193.9	2	Extreme bloating, t-shirt raised by bloat, maggots on underside of body, skin slipped off of feet arms and hands, eyes gone, ears gone, face disfigured
9/26/2001	206.1	3	Arms have been moved, bloating is dissipating, darkening of tissue, lots of maggots in mouth
9/27/2001	217.8	3	Further dissipation of bloating, holes in both feet, heavy fly activity, minimal maggot activity, animal damage to right arm
9/28/2001	231.7	3	Severely shrunken belly and it is greasy,
10/5/2001	343.3	3	Further deflation of abdomen, drying of all tissues, lots of gnat activity, feet slightly greasy, pelvis visible through clothing
10/9/2001	394.9	3	Further dissipation of bloating, maxilla and dentition visible, mold on left lateral side of abdomen and right arm
11/7/2001	794.2	4	Complete dissipation of bloating and further drying of tissue. Leaves have collected around body. No insects or maggots observed.

Figure 32: #31-01 on 9/15/2001. Stage I: Fresh

Figure 33: #31-01 on 9/20/2001. Stage II – maggots entirely cover the face and hair is starting to fall off.

Figure 34: #31-01 on 9/25/2001. Stage II – the shirt has been raised on the abdomen due to bloating.

Figure 35: #31-01 on 10/01/2001. Stage III – the abdomen is sagging and tissue on the arms and face is dry.

Figure 36: #31-01 on 11/7/2001. Stage IV – all exposed tissue is dry and hard.

Figure 37: #31-01 on 11/7/2001 after clothing was cut open.

many flies and yellow jackets swarming the body, and slight mold on the left upper thigh. Day two revealed oviposition in the mouth and ant or cockroach activity on the right arm. A mass of freshly hatched maggots was observed in the nose and ear on day three.

Day 10 (ADD 193.9) revealed extreme bloating of the entire body. As a result, the t-shirt had moved toward the head. Maggot masses were visible on the face and at the ground-body interface. The eyes were gone and the epidermis had slipped off of the feet, arms and hands. Stage III was reached the following day (ADD 206.1). Observations on this day included a dissipation of bloating, darkening of all exposed tissue and a large maggot mass in the mouth. Further deflation of the abdomen and a drying of all exposed tissue were observed on ADD 343.3. Additionally, the feet were slightly greasy, a great deal of gnats were swarming the body, and the innominates were visible through the clothing.

#31-01 reached stage IV on 7 November at ADD 794.2. No insects or maggots were observed on this day. All exposed tissue was dry and leaves had collected around the body. In total, #31-01 was exposed for 53 days and 794.2 accumulated degree-days.

V. DISCUSSION

Bodies initially exposed at the facility in the cooler months were more affected by animal activity than those exposed in warmer months (see figure 38 for weather data in the form of monthly high, low, and average temperatures). Animal activity at the facility was greater overall during this time as well. Racoons were observed frequenting the facility, as well as vultures and short tail shrews. Two raccoons were subsequently trapped and released at another location. This concurs with current literature that animal activity is amplified in winter months (see Bass 1997, Haglund and Sorg 1997, 2001). The three bodies placed during this time took on average 1600 accumulated degree-days to reach stage IV (see figure 39). All were nearly skeletonized with little tissue remaining. #23-01 was exposed during the warmest months of the year in East Tennessee (see figure 38). These high temperatures coupled with little rainfall resulted in the mummification of the skin on this body. Consequently, this body took 1072.2 accumulated degree-days to reach stage IV.

Bodies #30-01 and #31-01 were both placed at the facility in September. Temperatures were quite warm during the initial days after placement of both bodies, but soon turned cool. Both bodies reach stage IV with dry tissue and skeletonized facial regions. No animal damage was made to #30-01, and only slight damage was made to the right arm of #31-01. However, immense insect activity dominated the duration of the decomposition process in both bodies. Mummified tissue was found

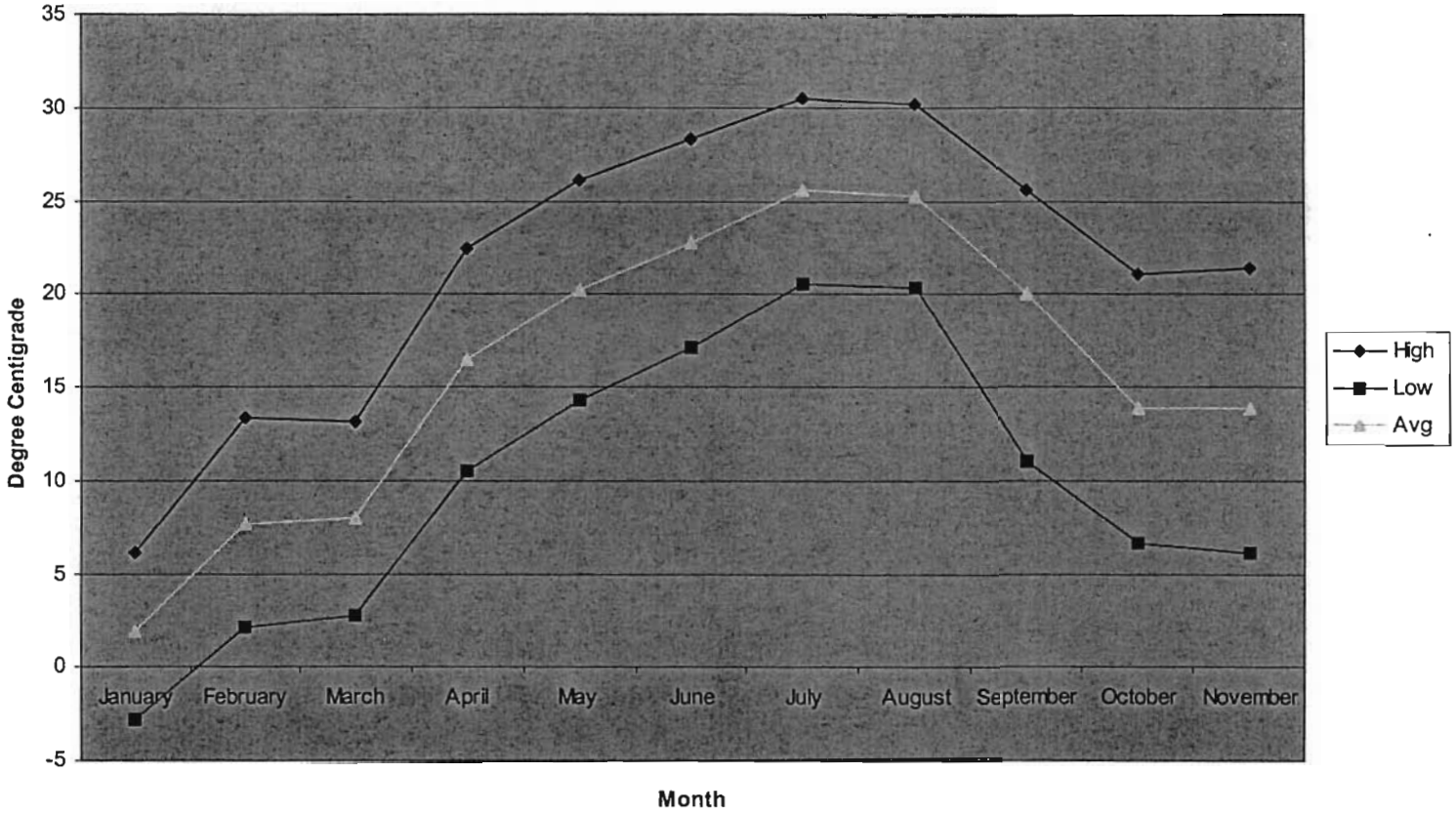

Figure 38: Weather data in the form of monthly high, low, and average temperatures.

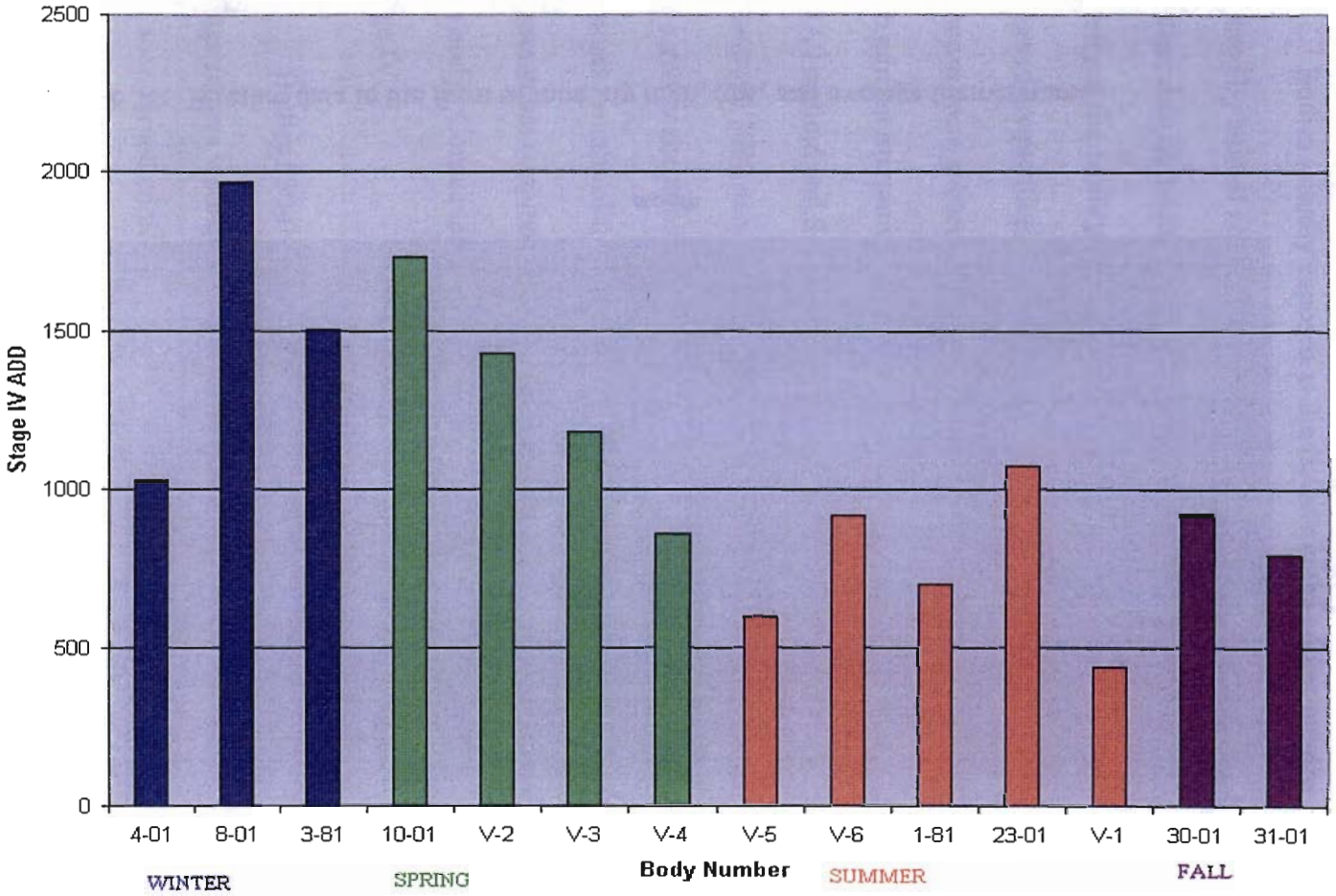

Figure 39: Comparison ADDs. Bodies beginning with "V" are from Vass (1991). 1-81 and 3-81 are from Watkins (1983).

adhered to the clothing in all subjects. In bodies #10-01 and #8-01, animal destruction to the limbs prevented observation of the natural decomposition process in the limbs. In bodies #4-01, #23-01, #30-01 and #31-01, mummified tissue remained on the limbs. Bodies #30-01 and #31-01 were placed at the facility ten days apart. #31-01 reached stage IV eight days after #30-01.

The ensuing changes of the six bodies used in this study were compared to bodies used in two previous studies (Vass 1991, Watkins 1983) using nude cadavers (see table 10). All comparisons are reflective of bodies that have decomposed at the Anthropology Research Facility. Accumulated degree-days were calculated for bodies in this study and for bodies used in Watkins' (1983) study based on criteria outlined previously (see table 1). Accumulated degree-days for cadavers used in Vass' (1991) study were computed by Vass using criteria outlined in his paper, which differed slightly from criteria presented here. The major difference is the definition of stages I and II. Stage I is the fresh stage and does not include insect activity. Stage I for Vass includes the initial signs of bloating as well as insect and maggot activity. However, criteria for reaching stage IV are nearly identical in both studies. Therefore, comparisons between all bodies were made using ADDs at stage IV only. No bodies in either of the two comparison studies were observed in the fall, preventing a direct comparison of ADDs for #30-01 and #31-01, both exposed during this time of year.

The two bodies used in winter in this study reached stage IV at 1031.7 and 1966.7 ADDs. #4-01 was much smaller in size than was #8-01, which could account for the variation in ADDs, so the average was taken for comparison. The average ADD is 1499.2. One body (V-2) used by Vass reached stage IV after 1428.1 ADDs and one used by Watkins (3-81) reached stage IV after 1503.4 ADDs. The average ADD for these two bodies to reach stage IV is 1465.8. Only a slight difference in accumulated degree-days required to reach the initial stages of skeletonization (stage IV) was found between bodies used in previous studies and ones used in this study.

One body in this study was exposed during the spring (#10-01). The accumulated degree-days required for this subject to reach stage IV was compared to two bodies used by Vass (V-3, V-4). #10-01 took approximately 1.7 times longer to decompose that these two bodies.

Only one body in this study was exposed during the summer (#23-01). Decomposition on this body progressed rapidly at first and then slowed tremendously. The skin eventually mummified and 1072.2 ADD were required to reach stage IV. These results were compared to one body used by Watkins (1-81) and three bodies used by Vass (V-1, V-5 and V-6). #23-01 took approximately 1.9 times longer than these nude cadavers to reach stage IV.

At the Anthropology Research Facility, numerous studies have been conducted on the process of human decomposition. Furthermore, many observations have been made on bodies that are placed at ARF to decompose which are not part of

any particular research project. Bodies that are not used for research purposes are placed at ARF and covered, usually with a black plastic body bag. This is done in order to accelerate the decomposition process so that the bodies may be processed and placed in the William M. Bass Donated Skeletal Collection in a timely manner. Bodies placed under body bags typically do not mummify. Instead, the entire dermis is consumed by insects, or decomposes naturally. Dr. William Bass, who is quite familiar with the decomposition process, expected clothing to act in the same manner (Bass personal communication 2001). That is, clothing would shelter the body from sunlight, allowing maggots and other insects to remain more active and consume all soft tissue. Instead, maggots created holes in the dermal layer and consumed soft tissue underneath. In a sense, they created their own protection. Sunlight and warm temperatures dried the skin, leaving it hard and eventually desiccated.

Clothing did not seem to have a noticeable affect on bodies in the winter. Animal activity was inhibited on the clothed portions of the body, but was not ceased.

In addition to observations, a general linear model was tested using the procedure PROC GLM in the statistics software program SAS. Clothing was scored as either absent (0) or present (1). Seasons were divided into three categories of temperature: (0) cold, which consisted of winter; (1) warm, comprised of spring and fall; and (2) hot, which included summer only. Temperature was found to have a significant affect on ADD at the .05 α level (see table 9). A second analysis was performed which tested the affect of clothing on ADD, controlling for temperature.

Table 9: SAS: The GLM Procedure

Dependent Variable: ADD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1338084.809	446028.270	3.85	0.0454
Error	10	1157384.088	115738.409		
Corrected Total	13	2495468.897			

R-Square	Coeff Var	Root MSE	ADD Mean
0.536206	31.45414	340.2035	1081.586

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Temp	1	1210962.513	1210962.513	10.46	**0.0090**
Clothing	1	79277.973	79277.973	0.68	0.4272
Temp*Clothing	1	47844.324	47844.324	0.41	0.5347

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Temp	1	754032.6550	754032.6550	6.51	0.0287
Clothing	1	2.5397	2.5397	0.00	0.9964
Temp*Clothing	1	47844.3240	47844.3240	0.41	0.5347

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		1451.152941 B	218.3048141	6.65	<.0001
Temp		-237.523529 B	202.1109847	-1.18	0.2671
Clothing	0	-1.443850 B	308.2280369	-0.00	0.9964
Clothing	1	0.000000 B	.	.	.
Temp*Clothing	0	-159.953743 B	248.7814246	-0.64	0.5347
Temp*Clothing	1	0.000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

Clothing was not found have a significant affect on ADD at the .05 α level (see table 10). Furthermore, controlling for temperature, the least squares means for nude and clothed cadavers was 1014.13 and 1171.53, respectively.

Although clothing did not have a statistically significant affect on ADDs required to reach skeletonization (controlling for temperature) the least squares means are moving in the direction of clothing prolonging the process of decomposition. Furthermore, the sample sizes used in this study were small, and discrepancies between the number of clothed and nude cadavers used in each season was apparent.

Table 10: SAS: The GLM Procedure – Controlling for Temperature

Dependent Variable: ADD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1290240.485	645120.243	5.89	0.0183
Error	11	1205228.412	109566.219		
Corrected Total	13	2495468.897			

R-Square	Coeff Var	Root MSE	ADD Mean
0.517033	30.60394	331.0079	1081.586

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Clothing	1	309300.4301	309300.4301	2.82	0.1211
Temp	1	980940.0554	980940.0554	8.95	0.0123

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Clothing	1	79277.9728	79277.9728	0.72	0.4131
Temp	1	980940.0554	980940.0554	8.95	0.0123

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1539.127500 B	165.5039420	9.30	<.0001
Clothing 0	-157.398750 B	185.0390324	-0.85	0.4131
Clothing 1	0.000000 B	.	.	.
Temp	-343.093000	114.6644945	-2.99	0.0123

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

V. CONCLUSION

Six unembalmed, unautopsied individuals were clothed and placed at the Anthropology Research Facility at the University of Tennessee, Knoxville at various times throughout the one year period of this study. The process of decomposition was observed and accumulated degree-days (ADD) were calculated. ADDs required to reach stage IV in all six bodies were compared with ADDs of nude bodies used in previous studies of decomposition at the Anthropology Research Facility. Furthermore, observations made on cadavers used in this study were compared with those made by other forensic anthropologists familiar with the process of decomposition.

There has been somewhat of a debate in the literature as to whether clothing accelerates or retards decomposition. Results of this study show that the presence of clothing prevents decomposition of the dermis and instead, accelerates desiccation, leading to mummification. Furthermore, the affect of clothing on the rate of decomposition is greater in the spring and summer than it is in the winter. A clothed body takes approximately 1.7 times longer in the spring and twice as long in the summer to decompose than a nude cadaver. However, the rate of decomposition is relatively the same for nude and clothed cadavers in the winter. It is unknown whether clothing is a significant variable in the decomposition process in the fall as there was no basis for comparison.

As has been shown in this study, clothing has a noticeable, though not statistically significant, affect on human decomposition and is a variable which must be considered when making an estimate of time since death. Forensic professionals who are called upon to make such an estimate are urged to take clothing and seasonality into account. The type of clothing associated with the discovered remains should aid in estimating the time of year the individual expired. Two notable exceptions are rape and homicide victims, and homeless individuals. Victims of rape and homicide are often thrown out nude, or with little clothing. Homeless individuals are known to dress in multiple layers throughout the year, making a season estimate difficult. In such a case, it is assumed that multiple layers would further curtail the decomposition process.

This study provides a baseline for making adjustments in time since death estimates on clothed individuals. However, more research on this topic needs to be performed. A study which directly compares the decomposition of bodies of equal mass and stature should be conducted with nude and clothed cadavers. This was the initial intent of this study. However, these circumstances are very difficult to arrange due to the nature of subject procurement. The Anthropology Research Facility relies on donations of bodies from individuals, and such donations cannot be orchestrated. Furthermore, keeping cadavers in a cooler for extended periods of time (while waiting for another donation) alters the soft tissue. Therefore, the results of research incorporating these bodies would be severely biased.

It is the hope of this researcher that continued efforts be made to study the affect of clothing, as well as other variables, on decomposition. Much progress has been made since Dr. William M. Bass founded the Anthropology Research Facility at the University of Tennessee Knoxville, but more research must be conducted before forensic anthropologists are able to fully understand the variables affecting decomposition. We will only be able to provide accurate estimations of time since death if we thoroughly understand the variables in the process of decomposition.

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