Raccoon Scavenging and the Taphonomic Effects on Early Human Decomposition and PMI Estimation

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DEDICATION

To Ma, my grandma, for her unconditional love throughout my life. I know she would be proud and pleasantly surprised that I ever went this far in school. Because of you, I've done everything but time and seen everything but the wind.

"I am a part of all that I have met"
~ Lord Tennyson Alfred

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ABSTRACT

Forensic investigators must consider the effects of numerous taphonomic variables when estimating the postmortem interval (PMI) in forensic cases, such as temperature and insect activity. Efforts to quantify the decomposition process have been made. Megyesi et al. (2005) modified the categories and stages of decomposition presented by Galloway et al. (1989), and introduced a total body scoring system that uses accumulated degree-days to estimate PMI. However, none of these systems include the potential effects of animal scavenging. Galloway et al. (1989) stated that carnivorous activity occurs mainly during advanced decomposition and mummification. Haglund et al. (1989) specifically investigated canid scavenging and disarticulation patterns on human remains. Reeves (2009) studied the impact vultures have on human remains and how that information can be useful to forensic investigations. Synstelien (2015) and Jeong et al. (in press) document raccoon scavenging and how their seasonal activity impacts soft tissue decomposition. All of these studies demonstrate that animal activity on human remains may have a significant impact on current PMI estimation methods.

This research investigates raccoon (*Procyon lotor*) scavenging during the early decomposition stage using daily photographs of ten individuals at University of Tennessee's Anthropological Research Facility. All of the individuals were scavenged by raccoons. The onset and duration of scavenging was recorded, and then all total body scores and accumulated degree-days (ADD) were

calculated using the methods set by Megyesi et al. (2005) to test for accuracy when including this variable in PMI estimation. The results of this research document how raccoon scavenging during fresh and early decomposition impacts estimation of PMI when applying Megyesi et al. (2005) total body scores and ADD calculations by causing accelerated skeletonization and mummification. It also stresses the importance of understanding the numerous variables that can influence the decomposition process (e.g. the relationship between scavenging and increased insect activity) that are not incorporated into current ADD calculations. This research demonstrates the need for understanding the numerous variables, including species-specific modifications, when estimating PMI in a forensic setting.

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CHAPTER I
INTRODUCTION

Introduction

Forensic anthropology has seen a recent surge in the past decade in attempts to narrow the windows of time since death and postmortem interval (PMI) estimates. It is important to understand the multitude of variables that impact decomposition rates and hence affect PMI estimation. Taking these variables into account offers better accuracy in PMI estimation, and the knowledge of these variables ensures forensic investigators are educated in the proper interpretation of crime scenes. Although temperature is one of the key variables affecting decomposition rates, recent research has focused on scavenging as a taphonomic event that can alter the rate and patterning of decomposition.

Taphonomy is the study of alternate processes that affect human remains after death, throughout decomposition and skeletonization. Taphonomic variables include weather, trauma, animal activity, indoor or outdoor environments, or any other factors that can affect and alter the natural process of decomposition (Sorg and Haglund 2002). The term taphonomy was coined in 1940 by Ivan Efremov and has become a vital element to the field of forensics when trying to reconstruct the process of human decomposition. With numerous variables affecting decomposition, understanding taphonomic effects on deceased human remains is important for determining a more accurate PMI (Ubelaker 1997), especially when a death has occurred under suspicious or unknown circumstances. Forensic taphonomy attempts to recreate the natural processes of decomposition that occur following death by focusing on the numerous factors that can affect the rate of decomposition. Recent taphonomic research has

examined an array of variables that can be useful in estimating PMI and encourages forensic anthropologists and investigators to keep their knowledge up-to-date when approaching crime scenes where deceased individuals are found.

Scavenging due to animal activity is one of many taphonomic variables that can affect the natural progression and rate of decomposition in both indoor and outdoor settings (Haynes 1982, Haglund 1997a, Komar and Beattie 1998, Berryman 2002, Klippel and Synstelien 2007, Steadman and Worne 2007, Reeves 2009, Ricketts 2013). This research focuses specifically on raccoon scavenging, and how their activity can alter the typical stages and patterns of human decomposition. The goal of this research is to attempt to compare decomposition rates to known standards and scoring systems used to determine stages of decomposition in forensic investigations today. Those standards were set initially by Galloway et al. (1989) and later modified by Megyesi et al. (2005); however, neither system included scavenging as a variable within their categorical systems.

Forensic anthropologists and investigators are frequently called upon to assess deceased human remains in various scenarios and in various stages of decomposition. To ensure accurate interpretation of these scenes, a well-developed knowledge of the variables that can affect human decomposition is needed. The information provided by this research will be complementary information to aid investigations with determining a more accurate PMI. This information will offer usable knowledge not only for forensic anthropologists, but also to law enforcement and medicolegal investigators who are ofttimes the first responders to a crime scene. It will also allow investigators to be better

equipped to interpret scenes in order to prosecute defendants in a court of law and to bring the perpetrators to justice for their crimes. However, in order for this information to be admitted in court as scientific testimony, empirical testing must have occurred. This research will demonstrate how variables challenge current methods used to estimate PMI. In 1993, the " '*Daubert* guidelines' " (Christensen et al. 2014:416), a result from the *Daubert v. Merrill-Dow Pharmaceuticals, Inc.* court case, dictated that any research must be tested using the scientific method; must be peer reviewed; must have potential or known error rates; must have applicable standards within the field; and must have been accepted within its relevant scientific community (Christensen et al. 2014). Since the information and total body scoring system modified from Galloway et al. (1989) and presented by Megyesi et al. (2005) is already permissible and being admitted in courts of law as a means of determining PMI, it is imperative that other variables affecting the rate of decomposition are tested and incorporated into this system for even greater accuracy.

Numerous variables exist when attempting to estimate PMI and it is important that a scene is viewed in a holistic manner. Scavenging of human remains by raccoons will be the focus of this research; however, the many other variables that can affect decomposition, especially in the early stages of decomposition, will also be addressed. Morton and Lord (2006) state that it is essential that more research on vertebrate scavenging is done so specific behaviors could be assessed throughout various regions of the United States to aid in decomposition research. Since this research focuses specifically on raccoons, which are found throughout much of the U.S., it is with hope

that this information will be useful in forensic investigations nationwide and give forensic anthropologists and medicolegal investigators the necessary tools to determine PMI more accurately.

CHAPTER II
LITERATURE REVIEW

Introduction

Variability in decomposition can be affected by numerous factors. Each of these factors must be considered when attempting to estimate postmortem interval when approaching the scene of discovery containing decomposing human remains. Not accounting for obvious variables at the site of discovery can present challenges in estimating time since death and allows for a greater margin of error. Although forensic anthropologists are needed to assist with recovering remains at the scene of discovery, they are not always called until after recovery has occurred and do not have the advantage of seeing the remains *in situ*, especially in circumstances where there is an abundance of soft tissue remaining on the decedent. However, just as context is stressed within archaeology when recovering either human remains or material artifacts, the entire context at the scene of discovery must be considered to lessen the margin of error and increase the accuracy of postmortem interval estimation.

At the time of discovery of decomposing human remains, the initial and most important factor to consider is the environmental context in which the remains were found. Of course, if the remains are skeletal, the next question to be asked is whether the remains are human or non-human. If the remains are determined to be human, it must be determined whether they are recently deceased individuals falling under the forensic investigative realm versus ancient remains falling under an archaeologically-based investigative realm. Once the skeletal remains are known to be of forensic importance, forensic anthropologists create a biological profile consisting of the individual's sex, age, stature, and ancestry estimates. The profile is then used to either

include or exclude individuals who may have been reported as missing. This process narrows down the number of potentially unidentified individuals and allows law enforcement to focus on particular attributes that aid in identification of the individual.

There are many cases, however, where individuals at the scene of discovery are in various stages of decomposition and have not yet progressed to complete skeletonization. It is in these instances that forensic anthropologists' presence at the scene can be useful in accounting for the numerous variables affecting the deceased individual's rate of decomposition. Current methodologies for estimating PMI have evolved since Reed (1958) used canine carcasses to study insect activity and Rodriguez and Bass (1983) studied decomposition on human donors occurring in four stages—fresh, bloated, decay, and dry. The more recent use of categories and stages of human decomposition described by Galloway et al. (1989) are shown in Table 1. These categories and stages have since been modified to include ambient temperature in order to calculate accumulated degree-days to reach a "total body score" for PMI estimation as shown in Tables 2-4 (Megyesi et al. 2005). However, past the brief mention of lividity in regards to the Fresh category stage "Fresh, no discoloration" by Galloway et al. (1989), and subsequently followed by Megyesi et al. (2005), there is no elaboration by the authors to describe the early processes of decomposition. The use of the phrase "no discoloration" can be misleading to anyone without prior knowledge or experience of the decomposition processes that occur near the time of death, especially when these processes (described below) may introduce numerous other variables in PMI estimation.

Table 1. Categories and stages of decomposition from Galloway et. al. (1989:609).

Category	*Stage*
A. Fresh	**1. Fresh, no discoloration** **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 dessicated 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**

Table 2. Categories and stages of decomposition for the head and neck from Megyesi et al. (2005).

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

Table 3. Categories for the Trunk from Megyesi et al. (2005).

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

Table 4. Categories for the Limbs from Megyesi et al. (2005).

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

Variables for Consideration

Antemortem Variables

Antemortem, or intrinsic, variables are conditions existing before death within the body that can affect the rate of decomposition. These variables can include an individual's body weight (whether emaciated or morbidly obese), or existing pathological conditions. Research by Zhou and Byard (2011) discusses separate case studies in which morbid obesity, diabetes mellitus, and sepsis each affected and accelerated the rate of decomposition with none of those cases involving extreme temperature differentials. Christensen et al. (2014) also mention bacterial infections as a condition that can alter or affect the rate of decomposition. Morbid obesity increases the insulating effect due to the high fat content and allows internal bacteria to continue to thrive for longer periods of time. Hyperglycemia in individuals with diabetes can accelerate fermentation within the body due to the increase in glucose; and bacterial infections can accelerate decomposition due to increased bacteria within the blood and/or organs (Zhou and Byard 2011). It is important to emphasize here that due to intrinsic factors, each individual "differs from body to body, from environment to environment and even from one part of the same corpse to another" (Campobasso et al. 2001). Although temperature is considered one of the key players in the process of decomposition, it is important to note the frequency in which other variables can change the typical process of decomposition either by accelerating or inhibiting its progression.

Perimortem Variables

Although much of the following information is usually determined by a pathologist or coroner who is called to the scene; understanding processes occurring at or around

the time of death (perimortem) allows for better understanding as to how decomposition rates may vary. In addition to the antemortem variables that can affect the rate of decomposition, perimortem variables can play a huge role as well. One well-documented perimortem factor that causes differential decomposition is trauma. Perimortem trauma includes blunt force trauma and sharp force trauma (e.g. trauma from hammers, knives, falls from heights, vehicles crashing into objects or pedestrians), or gunshot trauma. Berryman et al. (2013a, b) discuss the types of low-velocity trauma (blunt force and sharp force) and medium-to-high velocity force trauma (gunshot wounds) that can affect the rate of decomposition, especially when the trauma creates open wounds. Although research by Cross and Simmons (2010) and Simmons et al. (2010) argues that penetrative trauma does not alter the rate or pattern of decomposition, Huntington et al. (2007) discuss a case study where stab wounds allowed for heavier insect infestation in the wounds due to increased access to soft tissue. Additionally, Mann et al. (1990) discuss their observations of how quickly flies were attracted to a gunshot wound to the chest and began laying eggs immediately in the wound; Campobasso et al. (2001) reiterate that corpse integrity plays an important role in the decomposition process because wounds allow for additional sites of insect access and external bacterial growth; Christensen et al. (2014) state soft tissue injuries allow for additional portals of entry; Janaway et al. (2009:322) consider open wounds as “natural body openings” for Calliphoridae (blow flies) to lay eggs; and Wells and LaMotte (2010) and (Byrd and Castner 2010) specifically discuss insect activity and their attraction to wound sites.

Postmortem Variables

At the time of an individual's death, changes begin to occur and are referred to as postmortem changes since they occur after death. Postmortem variables include both the intrinsic factors already occurring within the body, and extrinsic factors that can further affect the rate and pattern of decomposition and complicate PMI estimation. These variables include The following sections may seem quite arduous; yet, they offer insight into the many intricate variables that occur at death but are seldom recognized or understood even when the death is witnessed, such as with individuals under hospice care, in a healthcare setting, or being attended to at home by loved ones.

Biological Processes at Death

Death does not occur at a specific time, however, is a process that occurs over time and includes processes of both somatic death, or death to the heart and lungs where circulation and respiration cease, and cellular death (Janaway et al. 2009, Mayer 2012, Wilson-Taylor 2013). During this process, chemical and physical changes are already occurring within the body that can affect the estimation of TSD and PMI in forensic cases. Although determination of time since death is typically determined by a pathologist or coroner, having a basic understanding of these processes and their differences can aid law enforcement and first responders in determining a truly "fresh" (i.e. recently deceased) individual versus remains that have progressed through the initial onset of decomposition to the more advanced stages.

The Agonal Period and Somatic Death

The agonal period, or the time during which an individual is actively dying, is the time frame that encapsulates the processes of death (Mayer 2012, Wilson-Taylor 2013).

Depending on circumstances surrounding an individual's death, this process can be drawn out due to chronic illnesses or be sudden such as those caused by fatal injuries (Mayer 2012). The agonal period includes the death struggle and death rattle that are both part of the dying process as organs begin to shut down and breathing becomes more labored. During this time the individual is inactive, may be unresponsive, and is said to be moribund, or dying (Mayer 2012). This period continues until the body is unable to sustain metabolic and physiologic activity and reaches somatic death. Somatic death progresses through stages of clinical death, brain death, and biological death, which in turn, lead to cellular death (Janaway et al. 2009, Mayer 2012, Wilson-Taylor 2013).

Clinical death is the cessation of both respiration and heartbeat, and is the time when somatic death can still be reversed by resuscitation (Janaway et al. 2009, Mayer 2012). Without resuscitation, brain death occurs, followed by biological death where organs shut down and cease functioning (Mayer 2012). Cellular death is a process that normally occurs in the body throughout life or as a result of disease; however, postmortem cellular death can extend over time as the cells still thrive on remaining supplies of oxygen and nutrients at the cellular level (Janaway et al. 2009, Mayer 2012, Wilson-Taylor 2013). Mayer (2012:110) gives examples of postmortem cellular death and the length of time that cells can continue to thrive after somatic death has occurred:

Brain and nervous system cells	5 mins
Muscle cells	3 h
Cornea cells	6 h
Blood cells	6 h

Mayer (2012) and Janaway et al. (2009) explain additional changes that can occur during the agonal period. *Agonal algor* is the cooling of body temperature before death that often occurs in deaths of the elderly and in individuals where metabolism has slowed. *Agonal fever* is the increase of body temperature prior to death that can stem from infection, poisoning, or toxemia. *Agonal hypostasis* occurs as blood begins to pool in lower portions of the body and can present conditions of lividity prior to death. *Agonal coagulation* is when blood begins to coagulate, or clot, thereby affecting circulation. *Agonal capillary expansion* occurs when capillary walls expand in attempts to allow more oxygen into the tissues. *Agonal edema* or *agonal dehydration* are caused by disease or capillary expansion where the tissues of the body either absorb increased amounts of moisture and fluids, or decreased amounts, respectively. Another aspect to be considered during the agonal period and after death is *translocation*, where microorganisms begin to move from their normal locations within the body to other locations since the body's natural defense mechanisms can no longer keep them contained. This movement of organisms can occur in several ways: by entering the circulatory system; by gravitation during hypostasis or changes in moisture content (agonal edema or dehydration); or by an organism's natural mode of motility (Mayer 2012).

Cellular Death and the Classic Triad

Once biological death occurs, the "well- documented changes known as the 'classic triad' of livor mortis, rigor mortis and algor mortis" (Janaway et al. 2009:314) begin to create physical and chemical changes within the individual. Physical changes

occur naturally within the body and are dependent upon natural laws such as gravity. According to Mayer (2012), there are physical changes that occur to the body postmortem in addition to those included in the “classic triad”: hypostasis, dehydration, coagulation of the blood, and endogenous, or internal, microorganism invasion. These physical changes occur due to surface evaporation, gravity, and cessation of the circulatory system to pump blood (Mayer 2012). Chemical changes are processes that occur due to chemical activity within the body and result in new substances being formed (Mayer 2012). Mayer (2012) also discusses five chemical changes that individually and collectively influence the body postmortem. Those changes include postmortem caloricity, postmortem stain, shifting in pH levels, rigor mortis, and decomposition.

Physical Changes

Algor Mortis

Algor mortis is the decrease of body temperature until reaching ambient level temperature. It is imperative that this process is considered in its application to a forensic context because remains found indoors will vary when compared to those found outdoors or inside a vehicle. The rate of cooling will be dependent on both intrinsic and extrinsic factors affecting each individual. Intrinsic factors include a weight and body mass-to-surface-area, body temperature at time of death (i.e. agonal algor or fever), or a combination of both body mass and temperature. As an example, an individual with more body mass (e.g. obese) will cool at a slower rate due to the insulating effect of adipose tissue, but an individual with more surface area to body

mass (e.g. infant or emaciated) will allow the temperature to decrease more rapidly. Activity prior to death, such as running or a struggle, may increase the body temperature before death (DiMaio and DiMaio 2001). Extrinsic factors are influences from the surrounding environment and can include clothing, coverings (blankets, tarps, etc.), and environment.

Hypostasis

Hypostasis occurs when blood gravitates to the lowest portions of the body and causes discoloration called lividity; however, if the body is left undisturbed lividity (Figure 1) can lead to postmortem staining (Mayer 2012). This settling of blood is dependent upon blood viscosity and body positioning at the time of death, (whether supine, prone, on its side, etc.). Contact palor is typically visually apparent during hypostasis and is caused by the decedent's own body weight pressing against another object inhibiting the blood from settling in that area (Mayer 2012). Areas exhibiting contact palor (Figure 2) will be significantly lighter and usually pale in comparison to the areas of the body where hypostasis occurred (Mayer 2012). Individuals with more viscous, or thick, blood will tend to take longer for blood to settle into the dependent parts of the body slowing down the process of hypostasis (Mayer 2012). Various factors influencing hypostasis are disease processes, medications, refrigeration, and temperature.

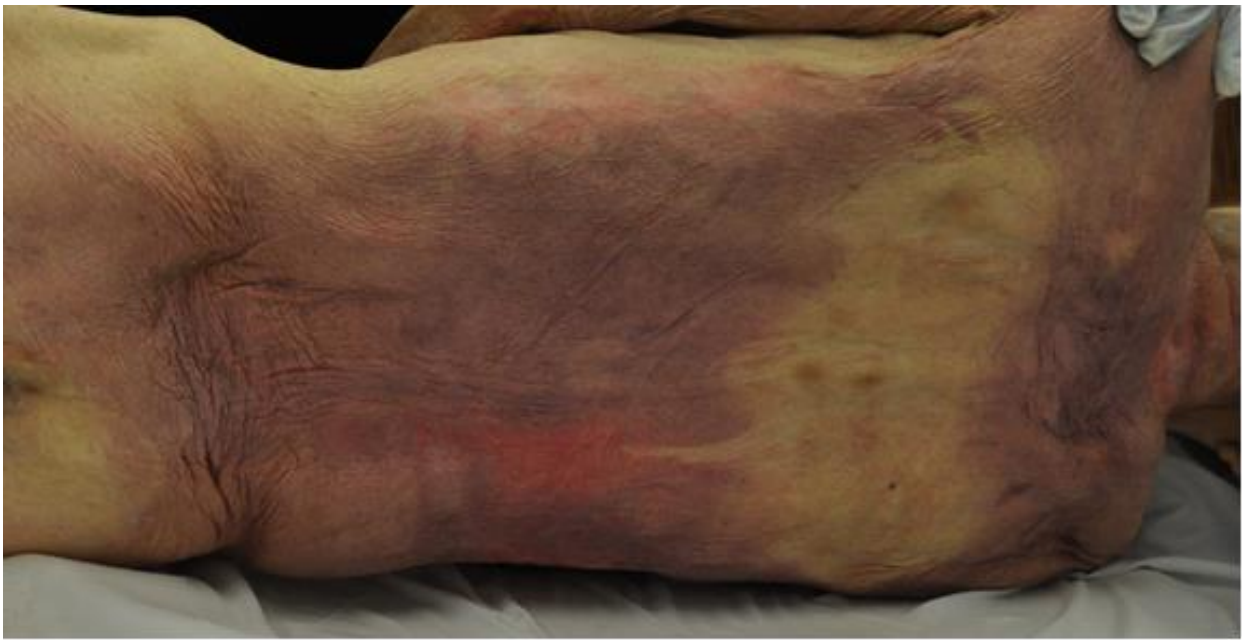


Figure 1. Postmortem lividity with contact palor in the scapular region on an individual supine at death (Courtesy of FAC).

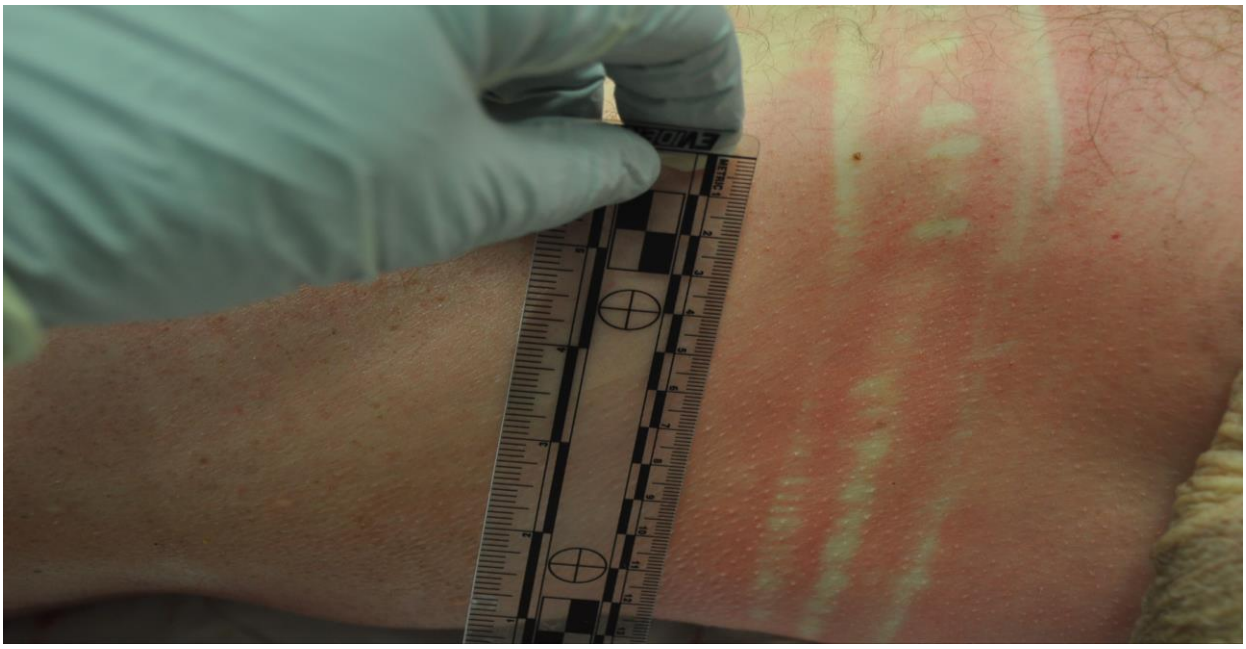


Figure 2. Contact palor exhibited on the right lateral portion of the hip due to compression of underwear (Photo by author).

Livor Mortis

Livor mortis is an intravascular discoloration of the blood that is the result of postmortem hypostasis, and results in staining of the lower parts of the body where blood has settled. This staining is also called postmortem lividity or cadaveric lividity and can occur as soon as ½ to two hours after death depending on the amount of antemortem and postmortem hypostasis (Mayer 2012). The amount of stain present on the body is influenced by blood volume and blood viscosity. In cases where there are either internal or external injuries causing blood loss, or in individuals with greater viscosity of blood, there will be less blood available to settle and this may lead to decreased staining or intensity when compared to an individual with less viscous blood or without injuries.

Dehydration and Coagulation

The gravitation of blood along with surface evaporation as air flows over the body can result in dehydration of the remains, especially on the skin and exposed surface tissues, since the tissues lose moisture content after death (Mayer 2012). Covering on the remains may help inhibit decomposition or accelerate dehydration dependent upon the type of material used (Dautartas 2009). As gravitational effects take place within the body and blood pools to the dependent areas, contact dehydration can occur in the higher portions leaving distinct and recessed, orangish-brown hues on the skin that will progressively get darker. Mayer (2012) also states that as the lower portions of the remains gain greater moisture content due to this gravitation, it is possible for postmortem edema to occur in those lowermost sections as the skin becomes over saturated with fluids and swells. As this gravitational effect continues, coagulation

(blood thickening) occurs intravascularly as the liquid portion of the blood separates from the solid portion through capillary walls and into the surrounding tissues.

Endogenous Invasion of Microorganisms

Once death occurs, microorganisms within the body invade other portions of the body through translocation (Marks et al. 2009, Mayer 2012). Mayer (2012:116) states, “Endogenous invasion of cerebrospinal fluid by bacterial agents associated with the colon occurs within 4 to 6 hours of death”. This translocation can be caused and accelerated by movement of the body or change in body position, chemical and physical changes that are naturally occurring, contaminated portions of the remains passively recirculating blood, relocation following fragmentation of thrombi, and the ability of intestinal microorganisms to move themselves (Marks et al. 2009, Mayer 2012, Hyde et al. 2013). Past research has focused on which microorganisms are active participants in the decomposition process (Vass et al. 2001, Janaway et al. 2009) and current research is now investigating individual “microbiomes” especially during more the progressed stages of decomposition, more specifically the bloat stage, that may yield greater accuracy in PMI estimation (Hyde et al. 2013, Metcalf et al. 2013).

Chemical Changes

Copious amounts of literature exist regarding the chemical changes that occur during decomposition so this section will be discussed with greater brevity. However, each change will be highlighted so the stages of decomposition can be introduced while continuing to stress the importance of understanding individual variations that can occur.

Postmortem Caloricity

As discussed above, once biological death occurs, the oxygen that remains in the body continues to sustain the cells until that supply is exhausted (Mayer 2012, Wilson-Taylor 2013). During life and at death while oxygen is still retained at the cellular level, cellular metabolism is maintained by two phases occurring within each cell. The anabolic phase is described as the building phase, and the catabolic phase is the breakdown phase of the cell (Mayer 2012). As this breakdown phase occurs, heat and energy are released from the cells and can cause an increase in body temperature after death. When this occurs, it is called postmortem caloricity, and this can accelerate the onset of both rigor mortis and decomposition (Mayer 2012).

Postmortem Stain

Livor mortis discussed above occurs intravascularly as the heart ceases beating and the blood begins to pool within the circulatory system. However, as cellular death continues the red blood cells break down further due to a process called hemolysis (Mayer 2012). Several million hemoglobin cells exist in each red blood cell, and during hemolysis the hemoglobin decomposes into heme and globin (Mayer 2012). Heme is the dark red portion of hemoglobin that leaves the circulatory system, seeps through the capillary walls and into the tissues. The early onset of this occurrence (half an hour to three hours after death) is lividity and these areas can typically be pressed using a finger and moderate pressure and blanching of that area will occur. However, as lividity progresses, approximately six to twelve hours after death (Harle 2012, Mayer 2012), this condition becomes fixed (i.e. no blanching will occur) causing postmortem stain on the individual. Forensic investigators may use the term lividity to encompass all forms of

discoloration due to the blood pooling in dependent areas. In attempts to cross-train individuals in terminology used in other professions, “postmortem stain” is often used to describe when the lividity can no longer be blanched from the skin when under pressure and is classified as “fixed” (Marks et al. 2009:171, Mayer 2012) which can aid in determination of PMI. As postmortem stain progresses further, marbling may become evident in various areas (Marks et al. 2009). However, it is important to note two factors that can accelerate postmortem staining: carbon monoxide poisoning and prolonged refrigeration (Harle 2012, Mayer 2012). Another type of extravascular staining that can occur in the same dependent areas as lividity and postmortem stain 18 to 24 hours after death are small petechial hemorrhages called Tardieu spots (Harle 2012, Mayer 2012). These small spots or “sometimes larger purpura patches of discoloration” (Mayer 2012:118) on the skin are the result of capillaries and small vessels rupturing, and are commonly seen in individuals dying by slower deaths or types of asphyxiation (Mayer 2012).

Changes in pH

For living individuals the normal pH (potential Hydrogen) within the body is 7.4, which is slightly above neutral (7) and considered alkaline or basic; below a pH of 7 is considered acidic on a scale from 0 to 14 (Mayer 2012). However, approximately three hours after death, the pH levels of the blood and fluids within the tissues drop into the acidic range as cellular death continues due to the depletion of oxygen and carbon monoxide levels rise (Mayer 2012, Wilson-Taylor 2013). As the pH levels drop into the acidic range, proteins within the body begin to break down. This process causes an

increase in ammonia and amines, alkaline nitrogen byproducts, which cause the acidic levels to become more neutral and progress to more alkaline levels where decomposition occurs (Mayer 2012).

Rigor Mortis

As death occurs, the muscles of the body are relaxed and in primary flaccidity (Mayer 2012). However, two to four hours after death, as the proteins within the body begin to break down and pH levels become more acidic (typically around 6.0), the muscles of the body stiffen causing a condition known as rigor mortis (Mayer 2000). Rigor mortis, commonly called “rigor,” is caused by the muscle fibers inability “to release from a contracted state” (Christensen et al. 2014) as adenosine triphosphate (ATP) is depleted and prevents the relaxation of muscle fibers until the muscles themselves begin to decompose (Harle 2012, Christensen et al. 2014). According to Nysten’s law, rigor initially sets superiorly in the body beginning in the eye muscles, face, jaw, and neck and progresses inferiorly to the upper extremities, trunk, then to the lower extremities (Harle 2012, Mayer 2012, Christensen et al. 2014). Dependent upon temperature and or disease processes, rigor is fully developed 6 to 12 hours after death and naturally passes from a body within 36 to 72 hours, known as secondary flaccidity. Variables that may cause the onset of rigor to occur more rapidly are infection, electrocution, strenuous exercise, terminal seizures, and high body temperature (Harle 2012). Ideal temperatures for rigor to occur are between 98°F to 100°F (36.6°C to 37.7°C) and the minimum temperature for rigor to set in is 32°F (0°C) (Mayer 2012).

Rigor dissipates more rapidly in hot weather, is halted above 120°F (48.8°C), and can persist longer than typical in colder weather (Harle 2012, Mayer 2012).

Active Decomposition

During decomposition there are two main processes occurring following the aforementioned physical and chemical changes: autolysis and putrefaction. Autolysis occurs while the body's pH is more acidic and the digestive enzymes within cells begin to consume the cellular material around them and self-destruct (Marks et al. 2009, Mayer 2012). This process typically begins in the abdominal cavity in organs that are rich in enzymes (e.g. pancreas, liver, and stomach) (Wilson-Taylor 2013). Putrefaction occurs as proteins within the body begin to decompose. As body compounds begin to decompose, they do so in the following sequence: carbohydrates, soft proteins, fats, hard proteins, and bones (Mayer 2012). Mayer (2012:121) also discusses the five "classic signs" that decomposition is occurring: color, odor, desquamation, gases, and purge. The right lower quadrant of the abdominal cavity is typically the first area of the body where decomposition occurs due to breakdown within the intestine and appears as a greenish hue on the abdomen (Figures 3-5). As proteins decompose they produce a distinct odor due to the breakdown of organic compounds (Mayer 2012). This discoloration in the abdominal region sometimes referred to as "green gut" can occur before death due to advances in the medical and pharmacological communities helping people to live longer and can predispose living individuals to early internal decomposition (Adams 2011). This discoloration can be found in both the fresh and early decomposition categories.

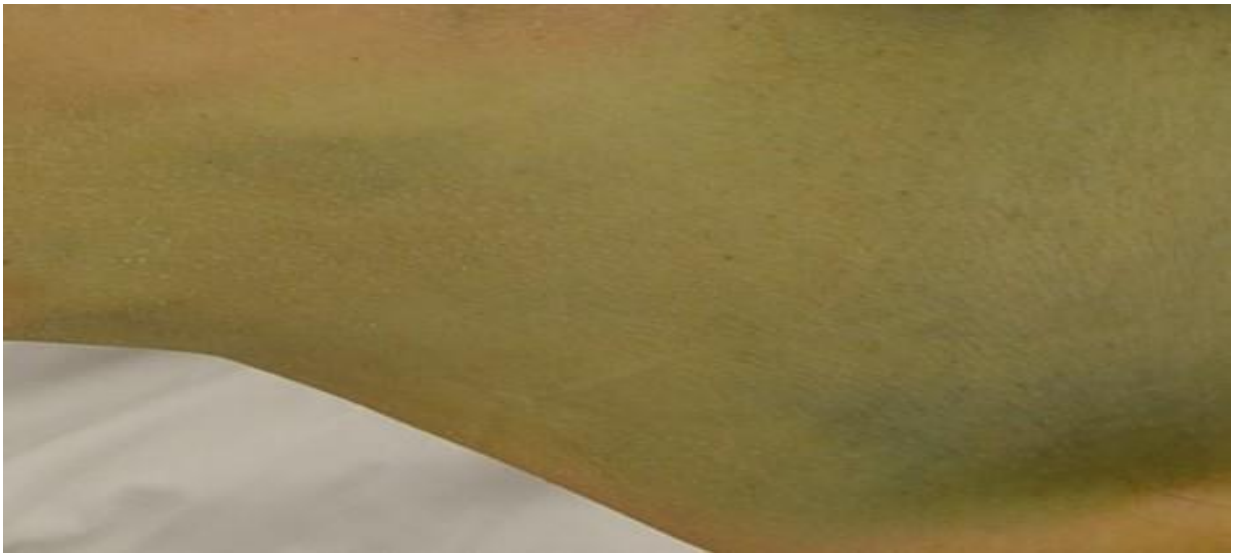


Figure 3. Light green hue in right lower quadrant of abdomen (Courtesy of FAC).



Figure 4. Slightly darker-green hue in right lower quadrant of abdomen (Courtesy of FAC).



Figure 5. Darker green-to-blueish hue in right lower quadrant of abdomen (Courtesy of FAC).

Desquamation, more commonly known as skin slippage (Figure 6), occurs as the outer layer of the epidermis begin to slough off forming blisters also depicted in figure 6, or bullae, that slough off the underlying dermis (Marks et al. 2009, Mayer 2012, Wilson-Taylor 2013). On the hands, this desquamation is called the “gloving effect” (Wilson-Taylor 2013:341) which can be observed as if gloves, in this case skin, were being removed from the hands; and on the legs and/or feet it is commonly called the “stocking effect” (Wilson-Taylor 2013:341) as the outer layer of skin sloughs off of the lower legs and feet. See Wilson-Taylor (2013) for further discussion. Skin slip is also a common occurrence on the scalp and causes the tissues and hair on the scalp to separate from the cranium (Wilson-Taylor 2013). This “hair mat” is often found at the initial site of deposition and decomposition due to increased maggot activity causing accelerated skin slippage and can be used in early decomposition PMI estimation (Wilson-Taylor

2013). It is important to note here that maggot activity can also cause skin slip without the blistering effect that may occur from the normal decomposition process (Figure 7). As maggots burrow in orifices (natural or from wounds), they will continue to visibly move beneath the epidermal layers causing separation of the epidermal and dermal layers of the skin (personal observation).



Figure 6. Desquamation ("skin slip") occurring over the body. Bullae noted with arrows (Courtesy of FAC).



Figure 7. Maggot activity separating the epidermal layer of skin from the dermis (Courtesy of FAC).

As decomposition accelerates, gases form in the abdominal cavity causing the abdomen to distend and become swollen (Marks et al. 2009). Although it has been stated that “limbs do not have a ‘bloat’ stage” (Megyesi 2001:19) and that “limbs do not bloat” (Megyesi et al. 2005:619), there are many instances, especially in cases of obesity and/or morbid obesity, where this distention and bloating can be observed in the arms and legs as well (Suckling 2011, personal observation) (Figures 8 and 9). As bloating continues it can cause these extremities to abduct, splaying farther away from the original position the body was deposited in, and may also cause the body to roll completely toward one side or the other especially if deposition occurred on a sloped surface (personal observation). As gases distend the body tissues, one can apply pressure to those parts and move, and sometimes hear the gases beneath the skin in a process known as crepitation (Mayer 2012).



Figure 8. Day 1: Donor placed prone; "fresh" with slight lividity on posterior (Courtesy of FAC).



Figure 9. Day 5: Same donor as above in "bloat" stage. Note the "stocking effect" on the feet and legs (Courtesy of FAC).

As the abdominal cavity distends to its limits without rupturing, force from this distention affects weaker areas such as the scrotum, eyelids, and breasts, and later the cheeks and lips, and can cause protrusion of the tongue (Marks et al. 2009, Mayer 2012, personal observation). Once the gases build up substantial pressure, they can cause purging, or elimination of liquids, semi-solids, or gases, from natural orifices (i.e. mouth, nose, and rectum) (Marks et al. 2009, Mayer 2012), then the body subsequently deflates as the decomposition process continues.

In forensic anthropology, the decomposition discussed above occurs during stages classified as “fresh” and “early decomposition” which includes the bloat stage where the body swells due to bacterial action and gaseous byproducts within the body (Reed 1958, Rodriguez and Bass 1983, Galloway et al. 1989, Megyesi et al. 2005, Marks et al. 2009, Mayer 2012, Wilson-Taylor 2013). As decomposition progresses, “advanced decomposition,” or the caving in/deflation of the abdominal cavity onto the skeleton, occurs. If decomposition progresses further before an individual is found, “skeletonization” and/or “extreme decomposition” occur (Galloway et al. 1989, Megyesi et al. 2005). However, there are other conditions that can occur during the natural process of decomposition. One such occurrence that is discussed in Galloway et al. (1989) but is excluded in research by Megyesi et al. (2005) is adipocere formation. Adipocere is more commonly known as “grave wax” that develops from the breakdown of lipids during the process of saponification, can complicate PMI estimations (Ubelaker and Zarenko 2011), and is known to occur in two forms. The first known substance is a result of “sodium’s reaction with interstitial fluid” (Wilson-Taylor 2013:342) that occurs

rapidly and its consistency has a hard and crumbly texture. The second type develops from potassium and its interaction with adipose tissue cells which forms into a “soft, paste-like variety” (Wilson-Taylor 2013:342). However, although the formation of adipocere may complicate PMI estimations, it can be useful in forensic investigations because of its long-term preservation. The preservative properties of adipocere can aid in the recognition of an individual thereby leading to identification and can also preserve perimortem injuries and toxicological evidence (Ubelaker and Zarenko 2011) thereby including or excluding certain unidentified victims of crimes. Adipocere can form in a variety of environments, although it is more common in specific body conditions where adipose tissue content is high such as in cases of obesity (Ubelaker and Zarenko 2011, Wilson-Taylor 2013).

Mummification is another process that does not conform to the typical stages of decomposition. Galloway et al. (1989) and Megyesi et al. (2005) include mummification in the advanced and skeletonization categories of decomposition. This process typically occurs when the soft tissues become dehydrated due to extremely dry conditions and arid environments such as those discussed in Galloway et al. (1989), where continuous air flow over the body desiccates the tissues, such as indoors with air conditioning/heat/fans running, outdoors with natural airflow passing over the body, or in scenarios where the body is clothed or wrapped in cotton materials (Dautartas 2009). In addition, the decomposition can restart if the body is subjected to rain or other sources of moisture that rehydrate the tissues and re-attract insect activity (Suckling 2011, D. Steadman, pers. comm.). When mummified remains are found, it is important to

consider the entire context *in situ* because the decomposition process may have been stalled for an extended, and typically immeasurable, amount of time.

Environmental and Contextual Variables

In addition to the many variables introduced by each individual, there are many other situations that present unique challenges in PMI estimation. Some of those variables include whether the remains were found indoors versus outdoors (Ritchie 2005) or in a vehicle (Voss et al. 2008, Anderson 2010); whether they were located on the ground, in concrete, interred in the ground (Henderson 1987, Weitzel 2005, Wilson et al. 2007), submerged in water (O'Brien and Kuehner 2007, Heaton et al. 2010), burned, or were found hanging (Anderson 2010, Wilson-Taylor 2013). Additionally, awareness of the local climate, regionality, temperature (one of the most influential factors in the decomposition process), season of discovery, clothing or material on or around the individual (Dautartas 2009), discernible obesity versus emaciation or height/weight proportionality, animal scavenging, trauma, and presence or evidence of insect activity are all useful means of narrowing the postmortem interval more accurately. Outdoor environments present different variables as opposed to indoor or vehicular environments that may inhibit initial insect access on deceased human remains (Voss et al. 2008). Unless a structure or vehicle has allowed for insect access (e.g. windows or doors open) insect activity will be minimized and can skew time since death because insect activity will not accelerate the decomposition process as it could in an unprotected environment (Ritchie 2005, Voss et al. 2008). Additionally, outdoor environments provide less protection from the elements and predators; therefore, it is

imperative that ambient temperatures are taken and any insect or scavenging activity is noted whether an individual is found indoors or outdoors, including scavenging that may have occurred by household pets (Galloway et al. 1989, Megyesi et al. 2005, Steadman and Worne 2007).

Temperature, Climate, Regionality, and Season of Discovery

Temperature is one variable that greatly affects the rate of human decomposition and is influenced by several other variables such as seasonality, ground or surface deposition, humidity, latitude, altitude, clothing and/or material encompassing the remains, air flow, and vegetation (e.g. sun versus shade) (Mann et al. 1990, Megyesi et al. 2005, Adlam and Simmons 2007, Dautartas 2009, Janaway et al. 2009, Vass 2011, Wilson-Taylor 2013). Warm temperatures introduce numerous factors such as increased bacterial and insect activity (Rodriguez and Bass 1983, Adlam and Simmons 2007), although extremely warm environments which lack humidity such as those discussed by Galloway et al. (1989) may actually inhibit bacterial growth thereby accelerating the process of mummification. Cooler environments, on the other hand, where temperatures remain at or below freezing can delay the onset of decomposition or prolong its process due to the inhibition of bacterial and insect activity.

Regionality and season seem to go hand-in-hand in terms of the variation in insect activity and the potential for scavenging. Galloway et al. (1989) describe the arid environment in Arizona and how extremely warm temperatures and low humidity cause mummification when remains are left exposed to outdoor environments, especially in the summer months. Insect activity was also noted to be seasonally affected with

Pharmia regina present in the winter, *Phaenicia sericata* in the spring, and *Cochliomyia macellaria* more prominent in the summer when temperatures reach over 38°C (100°F) (Galloway et al. 1989). Galloway et al. (1989) also discuss scavenging by carnivores, specifically by coyotes, and how they will often disarticulate the remains; remove those elements from the initial site of decomposition to take back to their dens or caches where the elements are consumed whole or in part; creating challenges for complete recovery.

In Central Texas, a sub-tropical region with alternating periods of humidity and drought, human decomposition research was similar to that found in Galloway et al. (1989) in regards to seasonality and aridity, and in some instances was well correlated with research by Galloway (1997) and accumulated degree-day (ADD) and total body scoring by Megyesi et al. (2005) (Parks 2011, Suckling 2011). Temperature and accumulated degree-day calculations using individuals with known dates of death allowed these studies to assess Megyesi et al.'s (2005) method for determining PMI in the early and advanced stages of decomposition, especially in instances where scavenging occurred (Suckling 2011). However, although the deceased individuals were subjected to the high Texas temperatures, the majority of bodies were protected from scavenging predators by "heavy-duty one-gauge welded wire rod" enclosures (Parks 2011:20, Suckling 2011) This point is important to emphasize when trying to incorporate the current standards for estimating PMI using the total body scoring system in conjunction with accumulated degree-days presented by Megyesi et al. (2005)

although scavenging has not yet been considered or integrated into this quantified method (Suckling 2011).

In Eastern Tennessee, temperature and seasonality also affect insect activity and are important factors in estimating PMI. In research by Rodriguez and Bass (1983) flies and beetles, *Diptera* and *Coleoptera* respectively, were the most frequent insects found associated with decomposing remains. Warmer spring and summer temperatures encouraged an abundance of insect activity which, in turn, led to accelerated decomposition where winter months inhibited much of their activity. Their research also demonstrates the pattern of insect succession throughout the various stages of decomposition.

Insect Activity

As mentioned above, warmer temperatures introduce yet another variable that arguably affects the rate of decomposition; however, this variable was not considered in the stages of decomposition in the research by Megyesi et al. (2005) that focuses on temperature alone—insect activity. Insect activity plays a vital role in the consumption of soft tissues throughout the process of decomposition. Maggot activity alone may present liquefaction of body parts that are not necessarily a result of purge from orifices such as the nose or mouth. Forensic entomology is a field dedicated to understanding how and when various insects typically invade soft tissues, and which insects play specific roles dependent upon the parsimonious relationship between the status of the remains (whether the remains are in early or advanced decomposition, mummified, skeletonized, etc.) and in regards to the byproducts of the remains upon the

depositional surface. Reed (1958) introduced research on the types of insects that were active in decomposition using dog carcasses. Since the time of that research, entomological data gathered for use in forensic investigations has soared and become one of the more accurate means of PMI estimation by using insects, larvae during various stages of development, and insect succession data. A copious amount of literature is available on this subject and *Forensic Entomology: The Utility of Arthropods in Legal Investigations*, edited by J. H. Byrd and J. L. Castner (2010), offers an easily accessible interpretation on the various insects that can affect, alter, and accelerate decomposition rates, especially when combined with ideal temperatures.

One of the most common insects that play a role in human decomposition is the blow fly, Calliphoridae. Temperature is one of the main variables affecting the rate in which flies oviposit on the remains; and when ideal temperatures exist flies can locate a body at the time of deposition and begin to lay as many as 180 eggs at a time (Rodriguez and Bass 1983, Janaway et al. 2009, Byrd and Castner 2010, personal observation). Oviposition by flies is both weather and temperature dependent. Heavy rains and colder temperatures will inhibit egg-laying, whereas, drier weather and warmer temperatures will encourage it (Campobasso et al. 2001). Open wounds allow for additional sites of oviposition in addition to the natural orifices they typically prefer and utilize (i.e. nose, eyes, mouth, rectum, genitalia) (Janaway et al. 2009), and offer additional and immediate food sources for the maggots throughout their stages of development. It is important to note that just as much as heavy rains can inhibit and disturb the typical oviposition process, open wounds and trauma where blood is deeply

pooled can also deter oviposition within the actual liquid (Figure 10). However, when there is a significant amount of pooling of blood, oviposition can occur as close as possible to the wound allowing for ease of access once larvae have hatched (Figure 11). Although flies and other carrion insects have received much of the limelight for the part they play in decomposition, there are other insects that take advantage of the food supply a deceased human body can provide as well. Ants have been photographed using bodies as food and housing sources when temperatures are too cold for typical fly activity (Figure 12). Bumble bees (*Bombus*), various butterflies (*Lepidoptera*), and yellowjackets (*Vespula*) (Figures 13 and 14) have also been captured in photographs possibly utilizing a “death nectar” (coined by author) as a source of nutrition on naturally decomposing and scavenged remains (personal observation).



Figure 10. Day 1: Flies attracted to wound site at placement on ARF surface (Courtesy of FAC).



Figure 11. Day 3: Oviposition at wound site (Courtesy of FAC).



Figure 12. Ants infesting the mouth during winter months (Courtesy of FAC).



Figure 13. A bumble bee (*Bombus*) drinking "death nectar" from an individual in skin slip (Courtesy of FAC).



Figure 14. Yellowjackets (*Vespula*) utilizing "death nectar" and meat/protein in addition to fly and larval activity on a scavenged limb in summer months (Courtesy of FAC).

As shown in the photographs, various insects may take advantage of the nutritional factors a decomposing body has to offer (Vail and Skinner 2000) whether through natural orifices or as a result of scavenging, hence the phrase “death nectar”. This semi-symbiotic relationship between insects and scavengers is important to recognize when attempting to estimate PMI especially when accounting for temperature. In addition, scavenging has also been documented at decomposition sites in research by Synstelien (2015) especially when the scavengers gather larvae or pupal casings of Diptera, Coleoptera, etc. for nutrition. Seasonal variation comes into play with each of these as well. Bumble bees (Bombus), yellowjackets (Vespula), butterflies (Lepidoptera), and mosquitoes (Diptera) are active during the warmer months when flies are also in abundance. However, ants are active even in colder months, climbing and consuming portions of the remains externally, leaving noticeably dehydrated spots on the remains (Haskell 1989, Haskell and Williams 2008, Anderson 2010, Byrd and Castner 2010, personal observation).

Scavenging

Scavenging is an important yet not fully-considered aspect of PMI estimation especially when it occurs during fresh, early, or advanced decomposition. Much research has been done describing the effects of scavenging on remains both indoors and outdoors, especially when considering the taphonomic results made on bone by scavengers (Haynes 1982, Haglund et al. 1988, Galloway et al. 1989, Haglund 1989, Galloway 1997, Haglund 1997a, Haglund 1997b, Komar and Beattie 1998, Berryman 2002, Klippel and Synstelien 2007, Steadman and Worne 2007, Reeves 2009, Ricketts

2013). Regional variation also exists between many of the types of scavengers discussed, especially in terms of forensic investigations. Regionality and climate are extremely important aspects in the interpretation of scavenging patterns in both terrestrial and aquatic contexts. Understanding how a particular species causes damage to both soft tissue and bone are vital especially when cases are isolated within specific locales throughout the United States (Galloway 1997). Vertebrate scavenging, however, has mainly focused on the damage caused to skeletal elements and differential decomposition on scavenged remains is not yet fully understood in regards to how it can affect PMI estimations during the early stages of soft tissue decomposition. Therefore, understanding these regional patterns and how they affect the rate of decomposition can assist with the interpretation of time since death estimation more accurately.

Canid scavenging is one of the well-documented types of scavenging in terms of the taphonomic processes they cause on bone, disarticulation patterns, dispersal patterns of skeletal elements, and relocation of elements. Steadman and Worne (2007) discuss a case in New York where a woman died inside her home, was scavenged and almost completely consumed by her two pet dogs (*Canis familiaris*) leaving little skeletal evidence behind. Research in Minnesota by Haynes (1982) discusses outdoor carnivores, timber wolves (*Canis lupus*) in particular, and how they take advantage of prey carcasses, yet, will consume frozen carcasses if a fresh carcass is not available. Coyote (*Canis latrans*) populations have been studied in the Pacific Northwest to better understand scavenging patterns (Haglund 1989), and in Massachusetts to better

understand the effects on scavenging and scattering of pig carcasses in order to correlate that information to infant and juvenile human remains in cases of child abduction and homicide (Ricketts 2013).

Avian scavengers have been documented to accelerate soft tissue decomposition to skeletonization within 48 hours. Reeves (2009) researched the effect of scavenging by American black vultures (*Corgyps atratus*) and turkey vultures (*Cathartes aura*) and found that their activity can "significantly accelerate the rate of decomposition" (Reeves 2009:527), and leave distinguishable markings on bone that can be useful when interpreting a crime scene. In Canada, studies by Komar and Beattie (1998) demonstrated how magpies were the first scavengers to feed on pig carcasses.

Research by Klippel and Synstelien (2007) describes the taphonomic effects of scavenging on bone by brown rats (*Rattus norvegicus*) and Eastern gray squirrels (*Sciurus carolinensis*). This research can be useful in forensic investigations and PMI estimations because it demonstrates that brown rats prefer greasy bone and eastern gray squirrels prefer dry bone. Therefore, depending on where a body is deposited (whether in full sun or shade), if skeletal remains are found with tooth modification identified as being made by eastern gray squirrel the individual had to be exposed to the elements long enough for the bones to lose their greasy content.

Northern Raccoons

Northern raccoons (Procyon lotor) are native to the North American continent and are free-ranging throughout the United States, southern Canada, and into Mexico

and Panama (Roussere et al. 2003, Souza et al. 2009, Synstelien 2015) .The majority of research on raccoons focuses on zoonotic disease processes carried and transmitted by the mammals such as rabies, Baylisascaris procyonis, an intestinal roundworm, and West Nile Virus (Roussere et al. 2003, Dietrich et al. 2005, Brown 2007, Souza et al. 2009, E. Patrick, pers. comm.). In addition to studies on disease transmission, literature can be found on raccoons as nuisance animals and how to discourage and/or remove them from urban areas and human dwellings since they are adaptable to various environments (Roussere et al. 2003, Souza et al. 2009, Wilson and Wolkovich 2011). Raccoons are dominant scavengers and one of the most abundant vertebrate mesopredators that perform “the critical ecosystem service [of] carrion removal” (Olson et al. 2012:77). Research on raccoons as dominant scavengers has also shown that their removal from terrestrial ecosystems can affect scavenging communities by allowing other scavengers greater opportunity to carrion (Olson et al. 2012).

Raccoons are highly adaptable to urbanization and although many animals are negatively affected by loss of habitat, raccoons have learned to thrive in both urban and rural environments (Beasley et al. 2007a, b, Synstelien 2015). Raccoons are avid scavengers, are quite resourceful in their foraging habits (Beasley et al. 2007a, Souza et al. 2009) and are “highly opportunistic, which allows them to exploit ephemeral resources” (Beasley et al. 2007b:844). Urban environments provide such opportunities with den sites, food resources, and reduced predation and hunting (Roussere et al. 2003). Availability to water and food influence raccoon movement, mating, and den selection, so if resources are seasonal their presence will be seasonal as well (Beasley

et al. 2007a, b, Synstelien 2015). In more rural areas, forested areas and areas with “woody cover” (Beasley and Rhodes 2007, Beasley et al. 2007a) are preferable to open land due to the availability of den nesting sites and foraging resources (Beasley et al. 2007a), and demonstrates habitat selection by female raccoons is attributed to maternal instincts for: shelter, resource availability, and ensuring the survival of their young.

Raccoons mate mid-to-late winter (typically between January and March). Female raccoons typically choose den trees to raise their young, or kits, after a sixty-three day gestation period and rear her young without the male or other raccoons until the kits are approximately two months old (Beasley et al. 2007a, Synstelien 2015). The mother takes the kits from the den, teaches them how to forage at night throughout the summer, and they stay with her approximately nine months during which time they learn skills necessary for survival. In the fall, raccoons consume extra food in order to store fat (in their tails) for the winter were they enter torpor, a stage of decreased activity, especially when temperatures fall below -9.4°C (15°F) (Nottingham et al. 1982).

Research into agricultural damage by Beasley et al. (2007b) demonstrates the seasonal effects of raccoon scavenging on corn. Beasley et al. (2007b) state that because of parturition and rearing of the kits, the females will stay close to known and available food resources especially during the maturation season of crops when they contain their most nutritious value. However, outside of agricultural areas where crop damage can be immense, raccoons have adapted to urban offerings from gardens, bird feeders, garbage, and pet food (Souza et al. 2009, Synstelien 2015). This type of scavenging, although a nuisance to many, is an important aspect to consider in the

food-web theory (Wilson and Wolkovich 2011). The classic version of this theory studied the lack of predation; however, the more modern version investigates scavenging and carrion consumption across ecosystems and its effect within ecosystems (Wilson and Wolkovich 2011). When considering raccoon scavenging on human remains during the early decomposition stage, the ecological impact within the food-web is important to consider.

When investigating decomposition, several researchers have conducted studies on carrion and the resource competition that exists between vertebrate scavengers, decomposers (invertebrates), and microbes (DeVault et al. 2003, DeVault et al. 2004, Burkepile et al. 2006, Olson et al. 2012). Raccoons are carnivorous vertebrates that use their forepaws and forelimbs to climb or scavenge for food with their five slender toes with sharp, non-retractile claws (Halfpenny and Bruchac 2002, Synstelien et al. 2015). Raccoons are omnivorous although they are ofttimes classified as carnivores, and will eat a variety of fruits, nuts, berries, fish, insect, snails, clams, etc.—including fresh carrion (Olson et al. 2012, Synstelien 2015). In addition to climbing, they use their front paws for a multitude of tasks including digging holes for crayfish or worms (Halfpenny and Bruchac 2002). This information on raccoons and their opportunistic nature is important when investigating both food resource and scavenging habits.

During early human decomposition, raccoons (vertebrate scavengers), invertebrates, and microbes are competing for the same food resource at the same time—a body, especially when temperatures are ideal (Olson et al. 2012, DeVault et al. 2004). DeVault et al. (2004:503) explain that except in very cold temperatures, animal

carcasses are usually consumed rather quickly after death and the scavengers that locate and use carrion as a food resource are typically the most successful of scavengers. DeVault et al. (2004) go on to describe how decomposers take advantage of fresh carcasses and oviposit minutes after death occurs and "liquefy muscle tissue as they feed" (DeVault et al. 2004:503); and how microbes enter the competition by producing dangerous toxins and "advertise their toxicity with various amines and sulfur compounds, which . . . repel vertebrate scavengers" (DeVault et al. 2004:503). Additional research by DeVault et al. (2003) also demonstrates that microbes monopolize carcasses in order to deter, or render the carcass inedible to, vertebrates with "*Clostridium perfrigens*, *Clostridium botulinum*, *Escherichia coli*, *Staphylococcus aureus*, *Shigella dysenteriae*, *Salmonella typhi* and *Bacillus stearothermophilus*" (DeVault et a. 2003:230) which are dangerous to both mammals and avian species alike. Therefore, if during the early human decomposition stage temperatures are ideal for scavenging, increased raccoon scavenging will be seen when there is less competition between decomposers and microbes, and less repetitive scavenging on an individual will be seen when temperatures are ideal for all three competitors. Vass (2001:191) states that, "Carnivore activity is yet another factor which can radically affect decomposition." However, although scavenging is readily acknowledged as an occurrence that can affect PMI estimation during soft tissue decomposition, research has not yet been well-documented as to how much it is affected in regards to the currently-used scoring method by Megyesi et al. (2005). Therefore, it is imperative that

research into scavenging, especially in the early stages of decomposition, be documented in order to assist in forensic investigations and PMI estimations.

CHAPTER III
HYPOTHESIS

In this research, raccoon scavenging is investigated to see whether there are differences when estimating PMI during early decomposition. Secondly, this study will focus on whether a commonly used decomposition scoring system can be effectively applied in early decomposition in the presence of scavenging. The null hypothesis is that there will be no difference in PMI estimation between known accumulated degree-days and calculated accumulated degree-days when raccoon scavenging is present. The alternate hypothesis is that there will be differences in PMI estimation between known and calculated ADD in the presence of scavenging. To accept the null hypothesis, no significant differences should be found in the presence of scavenging and ADD calculations. Otherwise, if significant differences are found, the alternate hypothesis should be accepted.

CHAPTER IV
MATERIALS AND METHODS

The Forensic Anthropology Center (FAC) oversees the Body Donation Program and Anthropological Research Facility (ARF) at the University of Tennessee-Knoxville. Individuals preregister with the program to donate their remains at death by completing a biological questionnaire consisting of vital statistic information, residence history, medical and dental history, and next of kin information (Shirley et al. 2011). At the time of death, the donor is brought to the William M. Bass Forensic Anthropology Building (Bass Building) for the "intake" process. During intake, the donor is assigned a unique UTID number. Full body and segmental photographs are taken of the individual to document the condition of their remains including teeth, any scars, discoloration, trauma, tattoos, personal effects, or any other notable conditions. Biological samples (e.g. hair, nails, and blood), cadaver weight, and cadaver height are also taken and the donor is placed into the cooler (maintained at 2.2°C or 36°F) until placement at the outdoor Anthropological Research Facility (ARF). At time of placement, the donor is photographed, and photographs continue to be taken daily until the remains reach skeletonization and their skeletal remains are recovered for processing. At processing, the skeletal remains are cleaned of any remaining biological tissue and the donor is accessioned into the Donated Collection in perpetual care to be studied in ongoing skeletal research (Shirley et al. 2011).

Individuals included in this study were selected using the University of Tennessee-Knoxville Forensic Anthropology Center's Donor Database from the years 2012 and 2013. Date of death, length of time held in refrigeration from place of death until being received at the FAC, date received at the FAC, date placed into refrigeration

at the Bass Building, and the date the individual was placed on the surface at the ARF are documented for all donations. Criteria for inclusion in this study were known date of death and daily photographs documenting the decomposition process. Additionally, any donors whose time of death was listed as “pronounced” or the date of death was listed as “date found” were excluded from this research to eliminate any questions arising from not knowing actual time since death.

Verification of weather data was made from the time of placement for each donor until time of skeletal recovery, unless the donor was still located at the ARF. The University of Tennessee Trial Gardens (UTTG) located directly across the Tennessee River from the ARF (Figure 15), or 1.4 driving miles away, provided the majority of weather data from the nearest National Weather Station (NWS) at McGhee-Tyson (TYS) weather station via National Oceanic and Atmospheric Administration (NOAA). If weather data was used from TYS due to missing data at UTTG, a ten-day prior and ten-day after correlation was made to ensure the weather data from both locales did not show significant differences; the greatest difference being $\pm$ 2.6° during the time period these subjects were studied. Additionally, research by Vass (1992) and Tomlinson (2003) previously tested for any temperature discrepancies recorded between these UTTG and the ARF, and although across the river from each other, no significant differences in those studies were found. The weather data consisted of minimum and maximum daily temperatures, in addition to rainfall and humidity, using 24-hour days from 00:00 to 23:59 as opposed to a set time collecting daily a.m. and p.m. temperature.

The FAC Photo Database was accessed to retrieve daily photos taken at the ARF consisting of up to ten gigabytes of photographs per individual. Any individuals who exhibited scavenging by animals or rodents other than raccoons were excluded from this study, and any individuals who were beyond the fresh stage and showed signs of decomposition at placement were also excluded.



Figure 15. University of Tennessee Trial Gardens and the FAC Anthropological Research Facility (Courtesy of Google Maps).

Ten donations were chosen based on verification of raccoon scavenging using the daily photographs and placement during four seasons. Each donor was then assigned a number 1-10. After issuing a research number, the photographs were then studied from the initial day of placement to skeletonization. These ten individuals were

recently deceased, with no more than fourteen days passing between the date of death and date of placement; ensuring refrigeration had been used to minimize decomposition. All individuals (n = 10) were of the same ancestry, scavenged, and placed prone upon the ground surface in various parts of the ARF. The PMI and information regarding sex, whether the donors were covered in black plastic sheeting or left uncovered, and whether autopsied or non-autopsied was gathered (Table 5).

Table 5. Donor Information

Individual	*Sex*	*Autopsy (Yes/No)*	*Covered/ Uncovered*	*Death to Placement (in days)*	*Season of Placement*
1	**Female**	**No**	**Covered**	**3**	**Spring**
2	**Female**	**No**	**Uncovered**	**1**	**Summer**
3	**Male**	**No**	**Uncovered**	**2**	**Summer**
4	**Male**	**No**	**Covered**	**3**	**Summer**
5	**Female**	**Yes**	**Covered**	**14**	**Summer**
6	**Male**	**No**	**Covered**	**11**	**Late Fall**
7	**Female**	**No**	**Covered**	**11**	**Late Fall**
8	**Male**	**No**	**Covered**	**2**	**Winter**
9	**Female**	**Yes**	**Covered**	**8**	**Winter**
10	**Female**	**No**	**Covered**	**7**	**Spring**

Additional information was also gathered including: the date of placement until raccoon scavenging occurred; the stage of decomposition the donor was in at onset of scavenging as defined by Megyesi et al. (2005) and completion of scavenging; the number of days scavenging continued; and any insect activity on the remains (e.g. oviposition, maggot activity, etc.). Since placement and daily photographs occur during daylight hours and scavenging occurs overnight; the first day of scavenging was calculated from the date of placement to the date photographs documented scavenging minus one day to account for overnight scavenging before daily photographs were taken the following day. If scavenging occurred within 24 hours of placement (i.e. overnight after the day of placement), PMI until scavenging is represented by 0.5 days.

Once the initial and final day of raccoon scavenging was documented, only the first ten days of scavenging were recorded on an adapted version of The Dodge Company Embalming Report Body Diagram (Figure 16) to demonstrate where scavenging originated and persisted. The body diagram shows the initial site of scavenging labeled as the “point of entry” (POE). The ten days were color-coded to coincide with: 1: Which day scavenging occurred on particular parts of the body (e.g. Day 1: Red, Day 2: Blue, etc.), 2: Whether the tissues were hollowed out and any bones were exposed due to scavenging, 3: Whether the body segments were skeletonized due to scavenging (literally skin and bone), and 4: Whether there were scratches made upon the remains without actual points of entry. Examination of the photographs revealed all soft tissue disturbances by raccoon occurred before the bloat stage, so early decomposition in this research is defined as ***pre-bloat***. Five bodies were not

scavenged for ten days because bloat occurred before Day 10 (e.g. if the individual was in bloat on Day 4, scavenging was recorded through Day 3 when scavenging ended). The body diagrams allow for a sequential and visual categorization of scavenged locations. The last date of scavenging documented on the body diagram was used to replicate a “date of discovery” in forensic contexts and calculations of total body scores (Megyesi et al. 2005) were made by me (Observer 1) for that day. ADD was calculated from the time of placement until the end of data collection in the 10-day scavenging window.

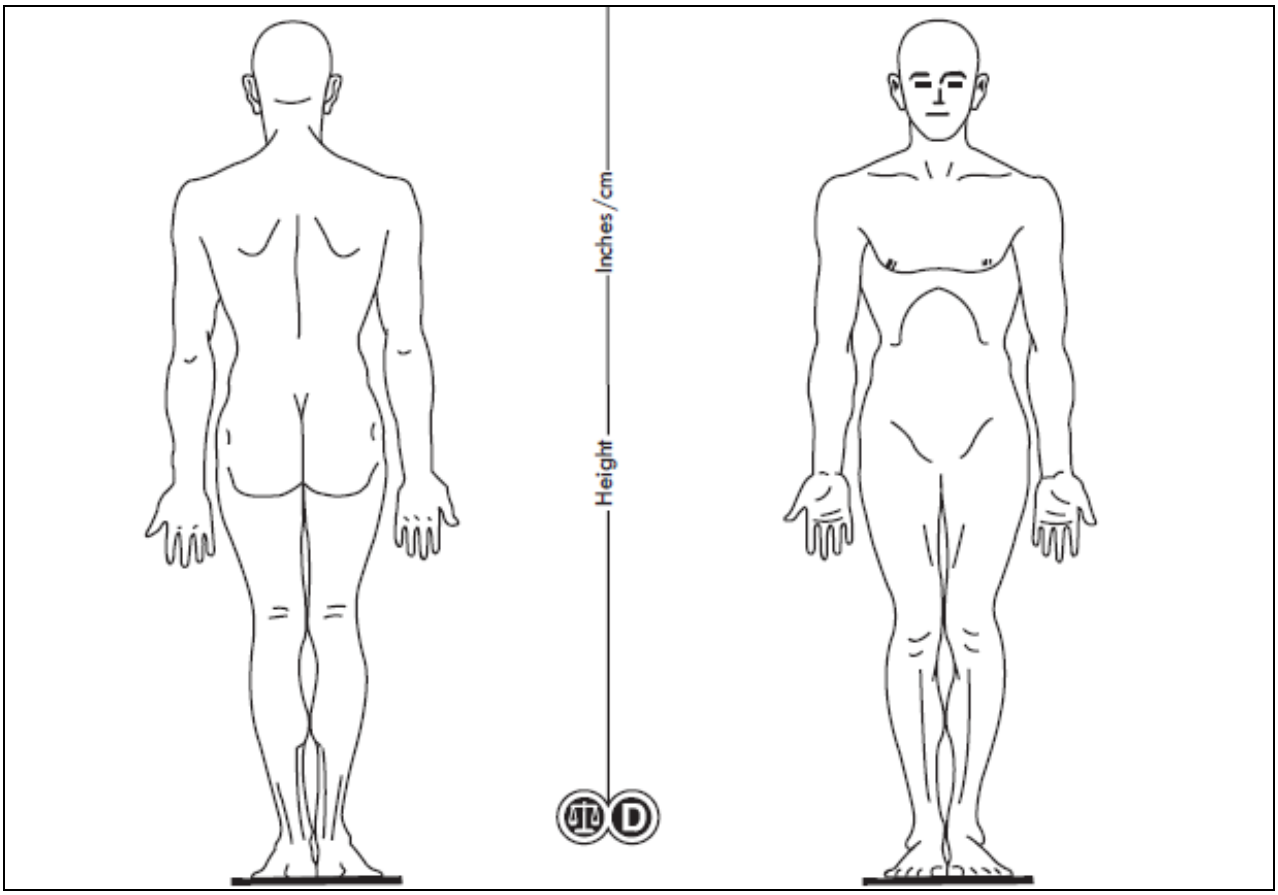


Figure 16. Body diagram adapted from The Dodge Company Embalming Report.

After calculating total body scores and ADD for each donor on the last day scavenged before bloat, all donors were then scored separately for interobserver comparison scores by an experienced colleague (Observer 2). The Observer 2 low score represents their score strictly following the rules set by Megyesi et al. (2005) that inexperienced investigators would use. The Observer 2 high score was the actual score Observer 2 believed to be best represented within the categories and stages presented by Megyesi et al. (2005). After scoring was complete, actual accumulated degree-days (ADD) calculations were made by averaging the daily high and low temperatures for each day since the date of placement. The sum of the daily averages represents the total, or actual, accumulated degree-days since placement. The actual accumulated degree-days were then compared to Observer 1 scores and Observer 2 low and high scores. Each of these scores was then compared to the estimated PMI according to the Megyesi et al. (2005) scoring system and the actual PMI.

The formula used to calculate ADD estimation using the sum of average daily temperatures is: $ADD= 10^{(.002*TBS*TBS+1.81)} \pm 388.16$ where $\pm$ 388.16 within the formula represents the standard regression error (Megyesi et al. 2005). All of the scores were calculated in Microsoft Excel. To test for interobserver differences, comparison of Observer 1 scores to actual ADD, Observer 1 to Observer 2 low, and Observer 1 to Observer 2 high was done using a Welch Two Sample t-test and Pearson's product-moment correlation computed using R (2013).

Verification of Raccoon Scavenging: Inclusion/Exclusion Criteria

Raccoons, as mentioned above, use their front paws for eating, climbing, and numerous other activities (Halfpenny and Bruchac 2002, Synstelien 2015). General observations and learning raccoon patterns and habits while working at the ARF for the past four years has assisted greatly in recognizing raccoon signatures when human remains are scavenged, especially in the fresh and early stages of decomposition. When raccoons initially approach a body that is covered in black plastic sheeting, they will either leave visible paw prints or will scratch through the plastic to access what is underneath and leave visible scratches on the body (Figure 17). If the individual is not covered in plastic, the paw prints will be visible upon the remains either in the form of mud, mold, or blood (Figures 18 and 19).



Figure 17. Scratches from raccoon curiosity (Courtesy of FAC).

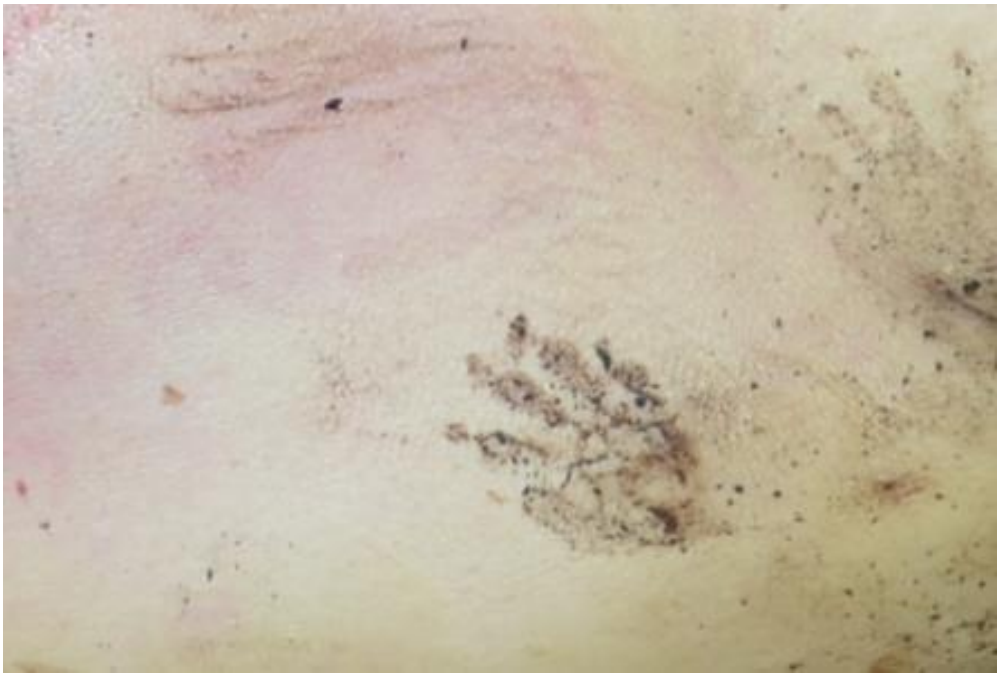


Figure 18. Muddy raccoon prints on posterior portion of remains (Courtesy of FAC).



Figure 19. Moldy raccoon prints on posterior of remains (Courtesy of FAC).

A deceased individual represents a source of nutrition to raccoons. The individual's limbs are scratched by the raccoons' sharp claws and bitten until the skin is broken and a larger hole is made in the soft tissue to allow access below the dermal layers (personal observation). In this retrospective study, the point of entry was consistently reutilized stretching the initial point of entry even wider allowing for more distal or proximal muscle extraction (Figure 20). Hollowing and deflation of the limbs became more evident as scavenging recurred (Figures 21 - 23). This pattern continued until: 1) Muscle mass on the individual was expended (often extending up into the gluteal region or down into the scapular region depending on where the point of entry was initiated), or 2) the body entered the bloat stage thereby deterring further scavenging. Skin slippage had not yet occurred on the majority of individuals when

scavenging began, and if it was present had barely begun to be noticeable. However, repeated raccoon activity did cause skin slip when the raccoons used portions of the remains as leverage to extract muscle from the body (Synstelien 2015, personal observation). Muscle tissue appeared to be the preferred resource over those of the dermal layers or internal organs since it contains high protein content and is more resistant to decomposition than the proteins that form other organs (e.g. brain, kidneys, liver) (Janaway et al. 2009).



Figure 20. Scratches and the initial point of entry (Courtesy of FAC).



Figure 21. Day 1 of raccoon scavenging with a point of entry on each leg (Courtesy of FAC).



Figure 22. Day 2 of raccoon scavenging with point of entry reuse and hollowing of each leg (Courtesy of FAC).



Figure 23. Day 3 of raccoon scavenging with point of entry reuse and more progressive hollowing and deflation of each leg (Courtesy of FAC).

CHAPTER V
RESULTS

General observations

Scavenging events for each individual were documented for the first ten days, (scavenging onset to Day 10) using the body diagram. The body diagram allowed for visual representation of raccoon return and/or repeated utilization as a food source. However, unless the donor went into bloat before those ten days were completed, all raccoon scavenging during early decomposition was documented until it ceased. The following data were documented: date of placement until raccoon scavenging occurred; the stage of decomposition the individual was in as defined by Megyesi et al. (2005) at the onset of scavenging; the number of days scavenging continued; stage of decomposition at completion of scavenging; and any insect activity on the remains (e.g. oviposition, maggot activity, etc.) (Table 6). Seasonal variation and insect activity was reviewed in order to see whether there was any correlation to scavenging and the onset of bloat. When sites of maggot activity were present they were monitored to record: 1) whether those sites were utilized by raccoons as access points to muscle, and/or 2) whether maggot activity increased from the creation of new and additional access points to internal tissues for larval development due to scavenging. Documentation of these events further examines the accuracy of current standards when computing total body scores using ADD by Megyesi et al. (2005).

Table 6. Donor Scavenging and Stages of Decomposition

Individual	*PMI until scavenged*	*Stage at onset of scavenging*	*Number of Days Scavenged*	*Stage at completion of scavenging*	*Maggot Activity at Onset of Scavenging*
1	**13**	**Fresh**	**12**	**Pre-Bloat**	**Yes, in elbow creases and face**
2	**2**	**Fresh**	**1**	**Pre-Bloat**	**Yes, in mouth and nose only**
3	**0.5**	**Fresh**	**6**	**Pre-Bloat**	**No, oviposition only on face and buttocks**
4	**1**	**Fresh**	**2**	**Pre-Bloat**	**No oviposition**
5	**0.5**	**Fresh**	**3**	**Pre-Bloat**	**No, slight oviposition in hair only**
6	**6**	**Fresh**	**7**	**Pre-Bloat**	**No oviposition**
7	**17**	**Fresh**	**10**	**Pre-Bloat**	**No oviposition**
8	**30**	**Fresh**	**24**	**Pre-Bloat**	**No oviposition**
9	**18**	**Fresh**	**35+**	**Pre-Bloat**	**No oviposition**
10	**23**	**Fresh**	**27**	**Pre-Bloat**	**Yes, light maggot activity on posterior**

Individual 1:

Placed in early spring, thirteen days passed before raccoon scavenging occurred. The average temperature from placement through the end of scavenging was 16.1°C (61°F). Initial scavenging occurred on the right hand and fingertips. Maggot activity was present in both elbow creases and in the face but was not extensive or present elsewhere on the body. On Day 2 of scavenging, three points of entry were observed on the left hand and upper arm and in the right arm where raccoons had

scratched and torn open the skin to gain access to muscle. Day 5 of scavenging progressed to bone exposure on both arms (Figures 24 and 25). On Day 6, both arms

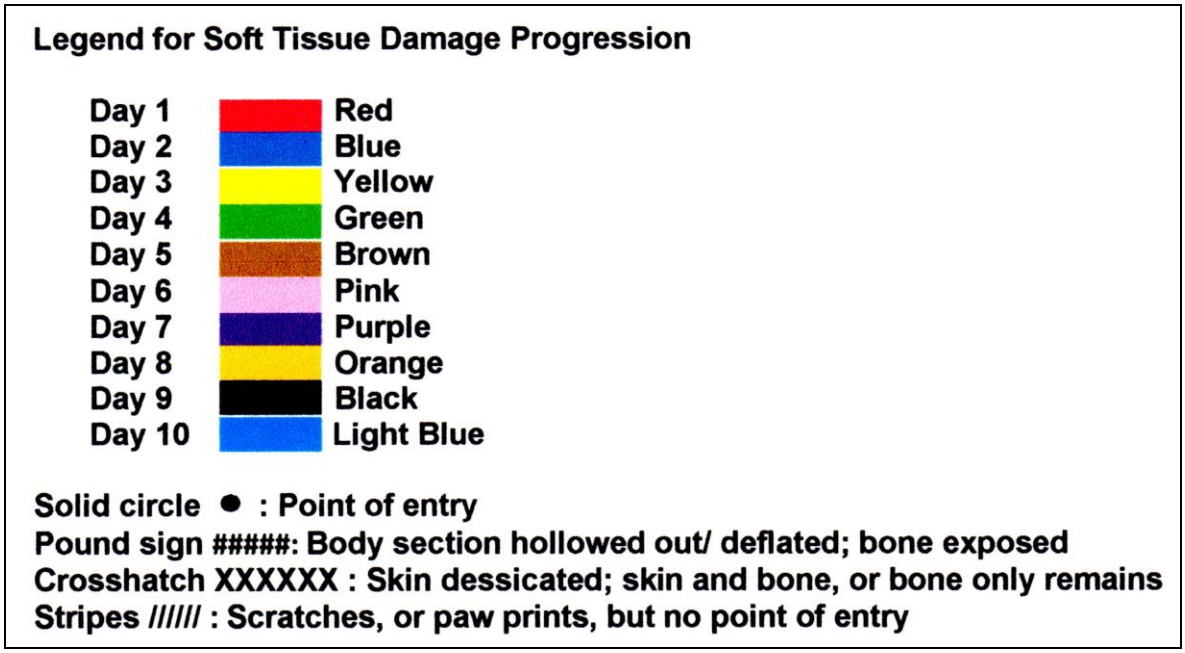


Figure 24. Legend for Soft Tissue Damage Progression.

and the right leg were hollowed out and deflated from the lack of muscle tissue and only the skin covering the bone remained. At the end of the ten-day observation period the individual had not yet entered the bloat stage, but maggot activity became more progressive, including at the sites of raccoon scavenging. The individual was scavenged for a total of twelve days. For this individual, Observer 1 total body scores and ADD calculations of 209.89 underestimated PMI according to the Megyesi et al. (2005)

scoring system. The estimated PMI suggests this individual was out half of the amount of time than the actual PMI of 24 days when compared to actual ADD (402.29).

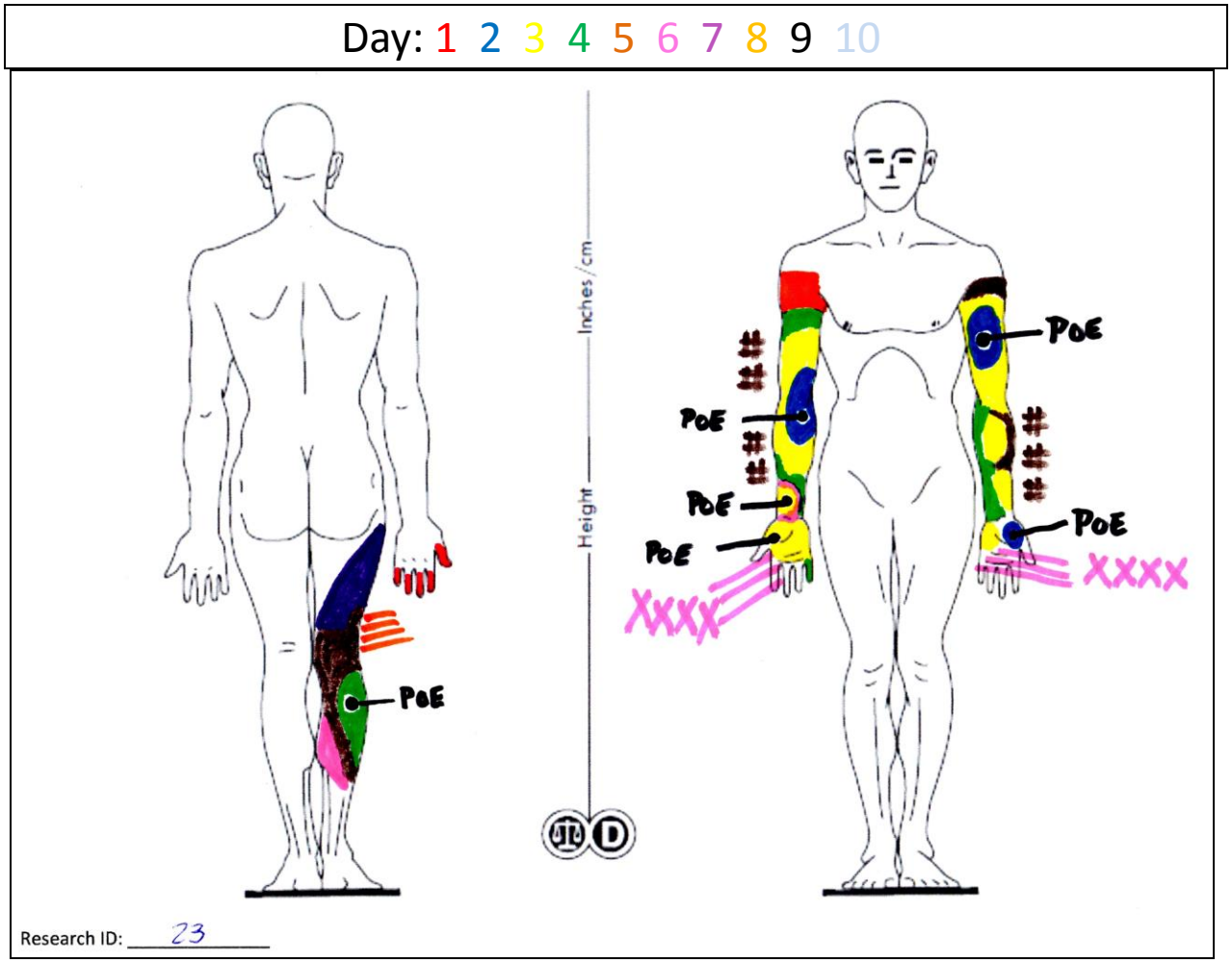


Figure 25. Individual 1 scavenged for twelve days.

Individual 2:

Scavenging on this individual began two days after summer placement and only occurred once. The average daily temperature for the three days was 28.2°C (83°F). Scavenging occurred only on the left limbs as skin slip was just beginning to occur on

the posterior portion of the remains. Points of entry included the anterior portion of the forearm exposing the radius and ulna; posterior portions of the upper arm exposing the humerus; the distal leg, and heel (Figure 26). Maggot activity was limited to the mouth and nose at time of scavenging. Bloat commenced the following day (Day 4). Observer 1 ADD (112.72) and actual ADD (112.71) were equal, with an estimated and actual PMI of three days.

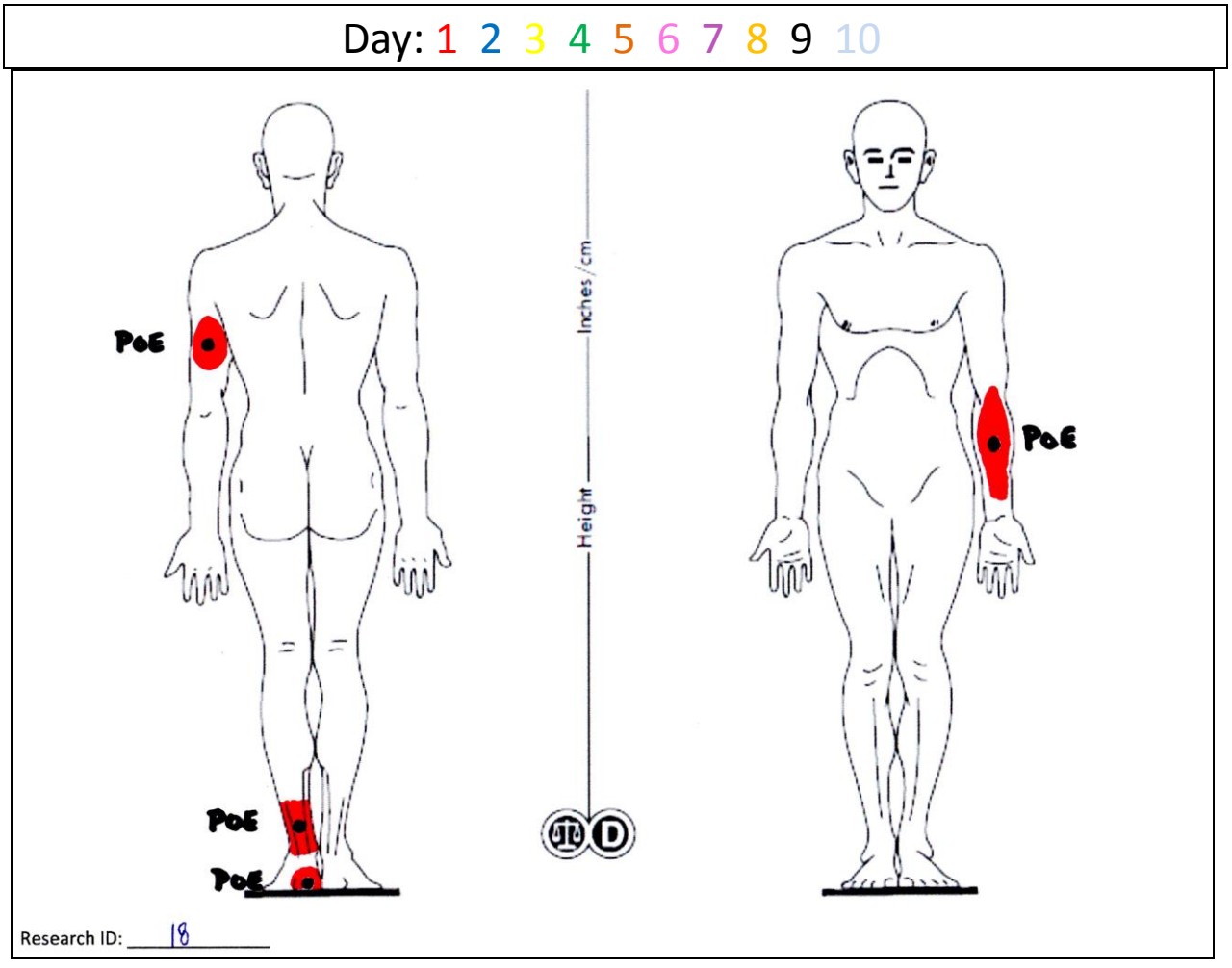


Figure 26. Individual 2 scavenged for one day before the onset of bloat.

Individual 3:

This individual was placed in the summer and scavenging occurred on the first night after placement (0.5 days). Points of entry on the first day of scavenging occurred on the anterior portion of the right forearm exposing bone and on the posterior portion of the right knee (Figure 27). Ten points of entry (POE) were recorded during the first three days following placement with bone exposure due to scavenging on Day 3 (Figure 28). As scavenging progressed, the limbs were progressively hollowed out and became more deflated as musculature was stripped from the bone. Oviposition and maggot development began in these hollowed areas and aided in the consumption of the remaining soft tissue. The remains were scavenged repeatedly and hollowing, deflation, and bone exposure were prominent on all limbs including the gluteal region as the buttocks were stripped of muscle. Scavenging ceased on Day 6 (Figure 29) before the bloat stage. Bloat did not occur on this individual due to extensive scavenging followed by maggot activity in the many additional access points, although the remains appeared to be “post-bloat” in the abdominal region by Day 11(not depicted on the body diagram). Observer 1 ADD (287.07) overestimated PMI suggesting they were out longer than the actual ADD (185.89). Actual PMI was six days.

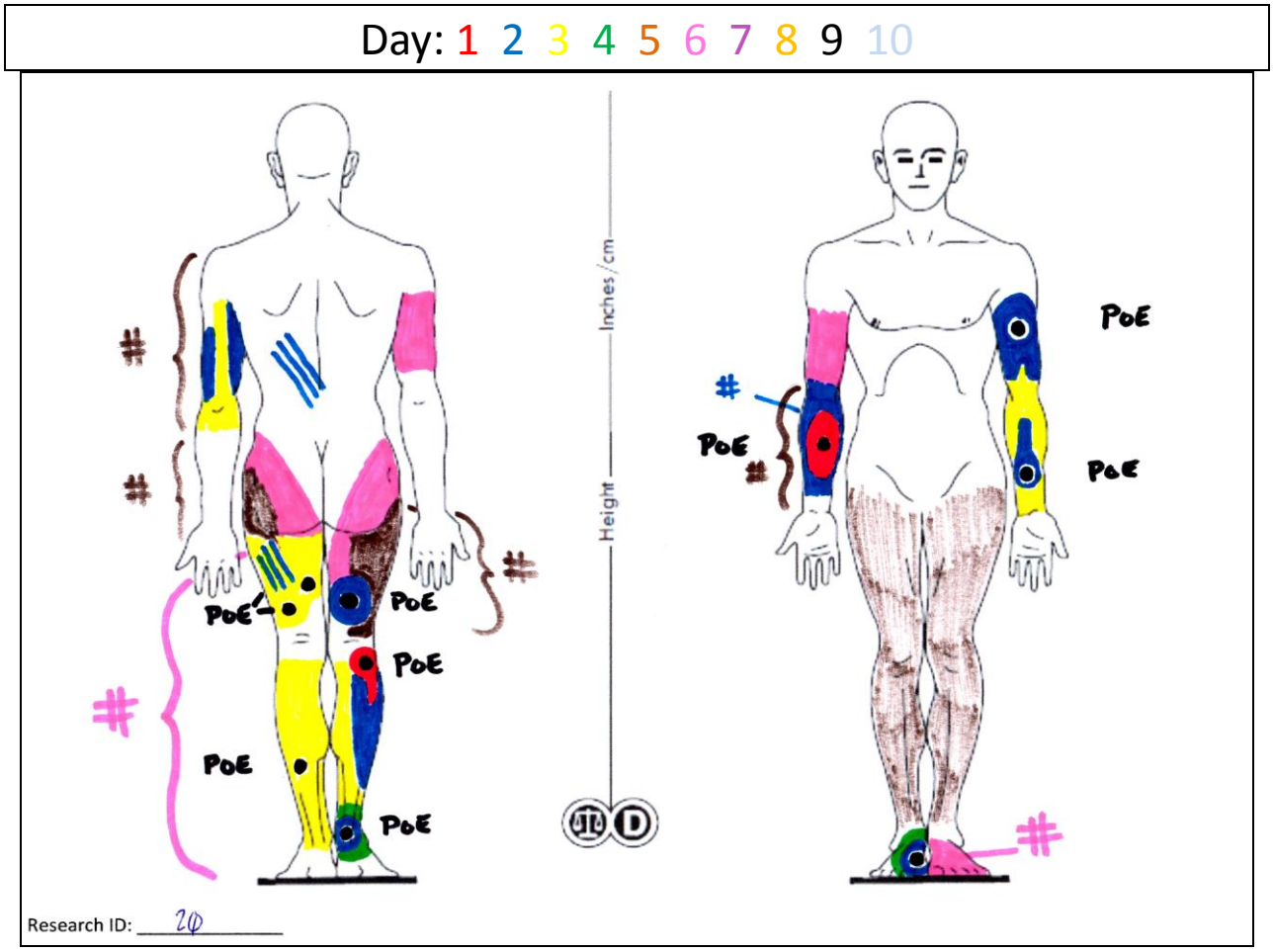


Figure 27. Individual 3 scavenged for six days.

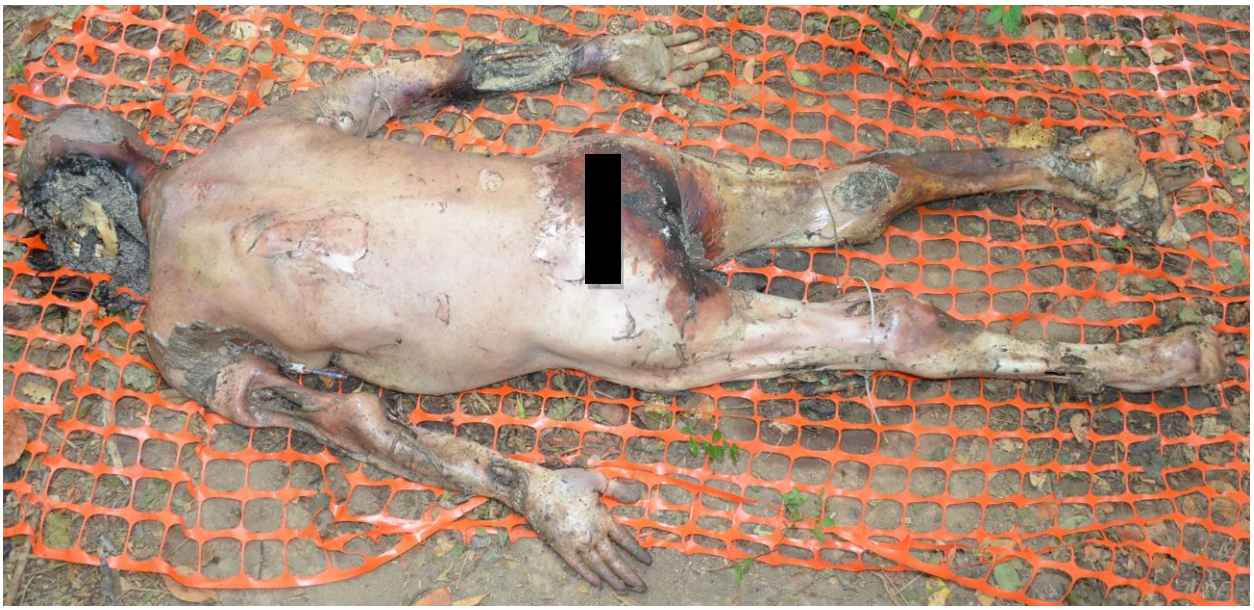


Figure 28. Individual 3 with bone exposure on Day Three.



Figure 29. Individual 3 on Day Six.

Individual 4:

Individual 4 was scavenged one day after summer placement with three points of entry occurring at both anterior and posterior elbow joints (Figure 30). Scavenging occurred for two days with Day 2 resulting in the hollowing of muscle, deflation of the epidermis and dermis, and bone exposure in the right arm. Both lower legs exhibited green discoloration, while the upper legs and torso still presented as “fresh.” There was no oviposition upon the remains until Day 3 and the remains still appeared fresh. By Day 4 skin slippage was apparent, the body was in full bloat; and although maggot activity was extensive, minimal hair loss had occurred. Observer 1 ADD (112.72) was over actual ADD (107.54) slightly overestimating the estimated PMI. Actual PMI was three days.

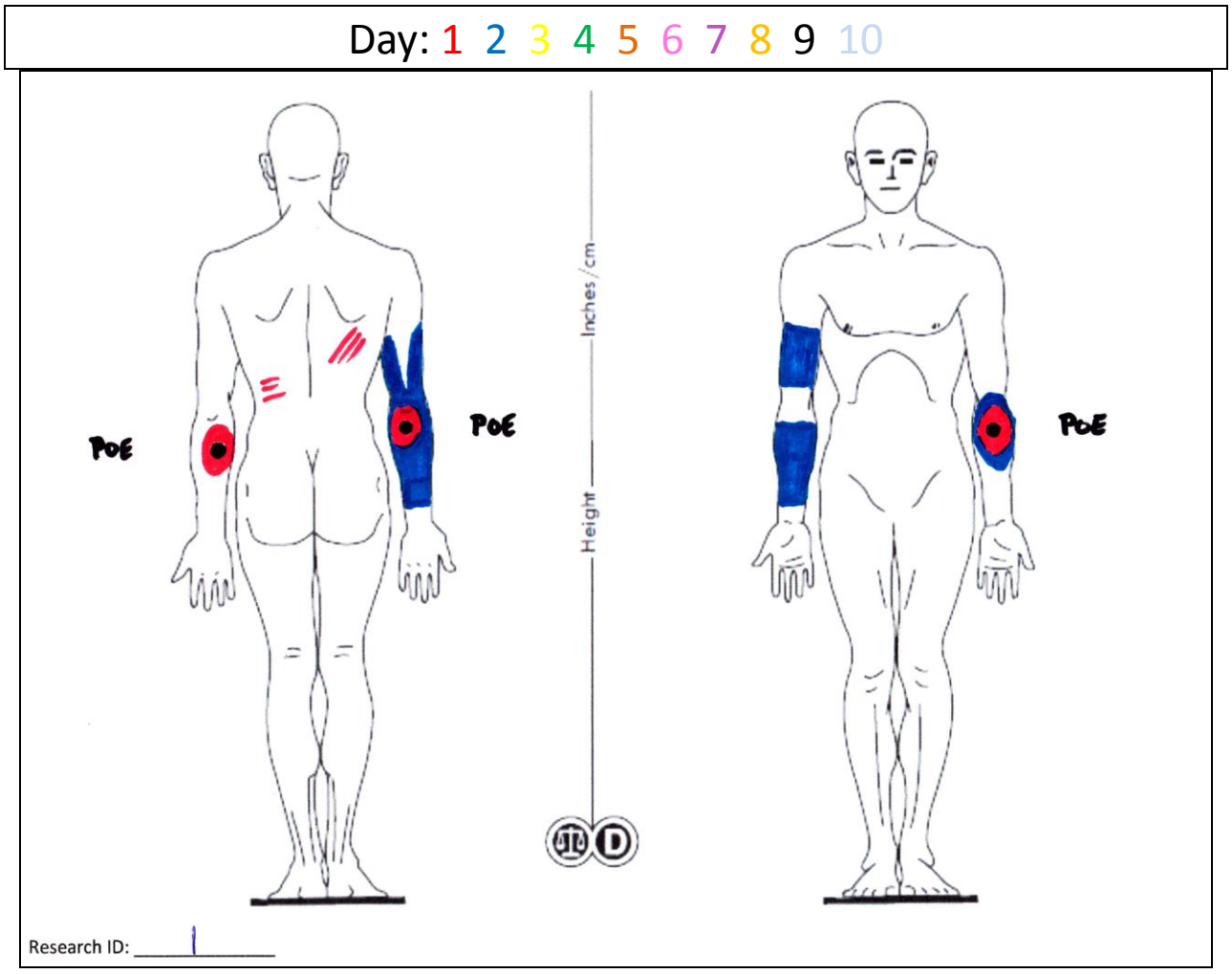


Figure 30. Individual 4 scavenged for two days.

Individual 5:

Scavenging occurred on the first night after placement on the right hand (Figure 31). The fingertips were chewed and acrylic nails were removed and left on the ground below the hand. No oviposition was on the remains except for a slight amount in the hair. Scavenging continued for two additional days. On Day 2 a POE was noted on the right forearm with musculature stripped away and further hollowing and deflation

continued distally to the wrist and proximally to the shoulder joint through Day 3. This donor was autopsied; however, no disturbance occurred in the thoracic or abdominal cavity although the region was easily accessible. The hair mat sloughed off the cranium on Day 4 and oviposition and maggot activity was more intense throughout the body. By Day 5 the calotte (cranial cap removed for cranial autopsy) had fallen away from the remainder of the skull, and by Day 6 maggot activity had moved the calotte further away from the rest of the skull (Figures 32 and 33). In addition, although the thoracic and abdominal cavity was open due to the autopsy procedure, the body still entered full bloat and was almost completely lying on its side on Day 5 during the bloat stage. Observer 1 ADD (125.31) slightly overestimated PMI when compared to the actual ADD of 107.62. Actual PMI was three days.

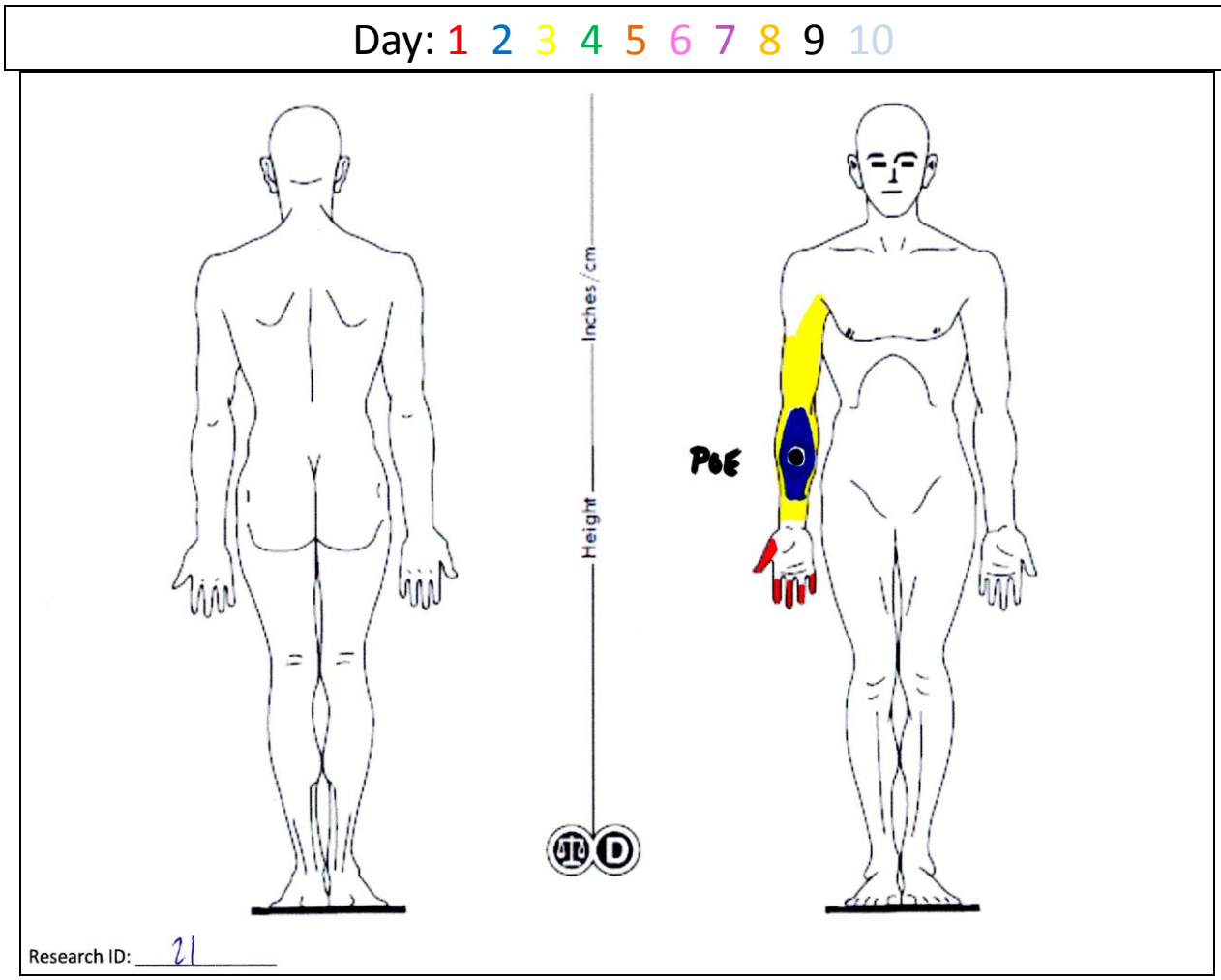


Figure 31. Individual 5 scavenged for three days.



Figure 32. Individual 5 with calotte dislodged due to maggot activity (Courtesy of FAC).



Figure 33. Individual 5 on Day Six with calotte moved farther away from skull due to maggot activity (Courtesy of FAC).

Individual 6:

Placed in late fall, this individual was scavenged six days after placement and scavenging occurred for seven days (Figure 34). On the initial day of scavenging scratches were apparent on the face and the mouth was used to reach in and pull out the hyoid bone which was left on the ground near the head. No oviposition was present on the remains; however, this individual had an ant infestation in the mouth. The second day of scavenging was on the right foot, and progressed to three POE on Day 3 with extensive hollowing and deflation of the upper legs and both arms, with bone exposure, and scavenging on the left ear. Day 4 the left gluteal region was stripped of muscle, as were both legs more distally (at and below the knee), and the left scapular region was stripped of muscle as well. By Day 7, skin slip had not appeared on the remains except on the left lower posterior region where raccoon activity had occurred while using the body as leverage to extricate muscle from the gluteal region (Figures 35 and 36). Bone exposure was present in all the limbs, hollowing and deflation was evident, and for the majority of the limbs, with the exception of the hands and feet, only skin and bones remained. The remains did not enter bloat, oviposition did not occur, and the remains became mummified. Observer 1 ADD was 140.60, underestimating PMI when compared to actual ADD (227.07). Actual PMI was 23 days.

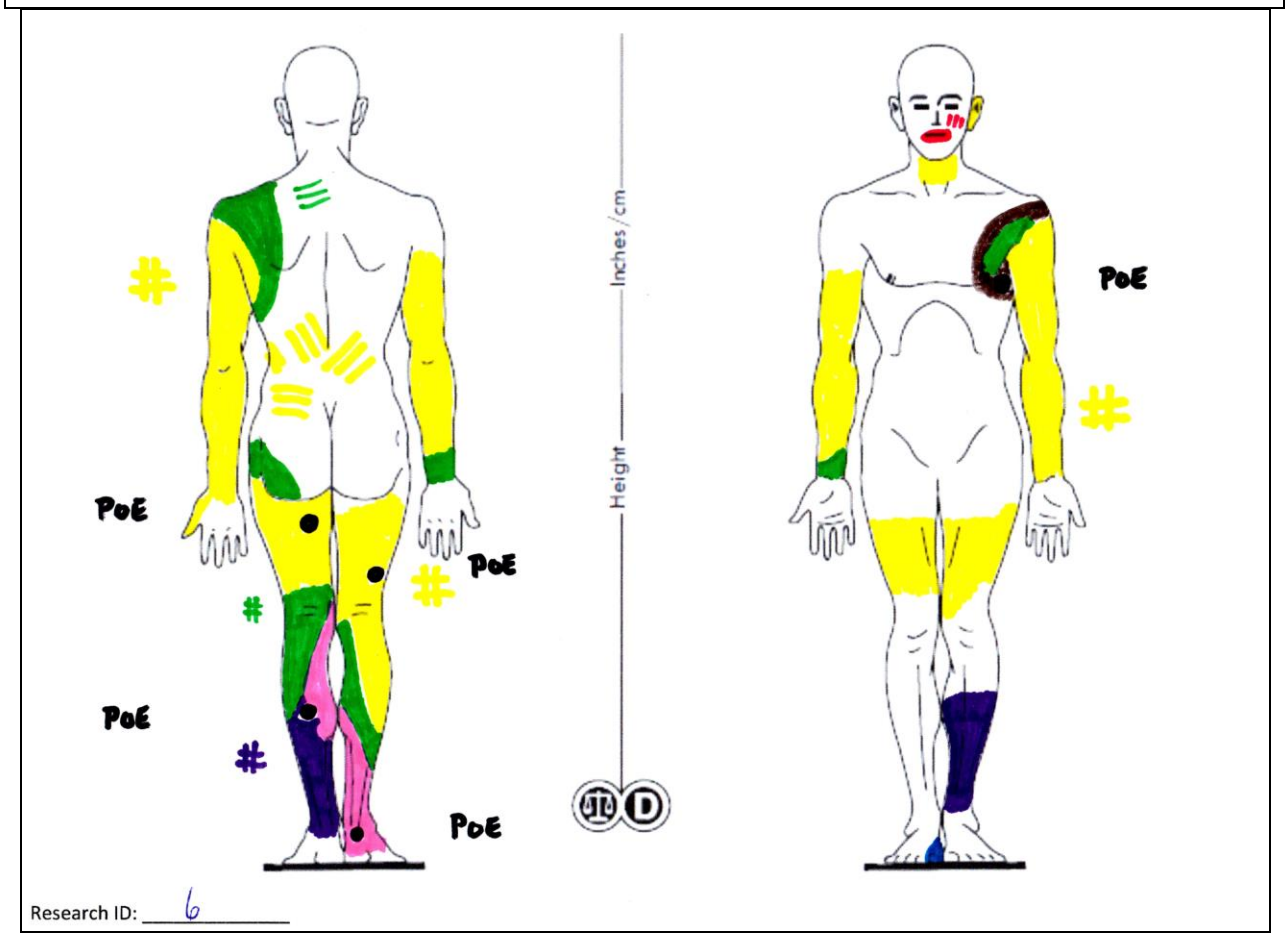


Figure 34. Individual 6 scavenged for seven days.



Figure 35. Individual 6 on Day Seven with extensive hollowing of the limbs, deflation, and skeletonization (Courtesy of FAC).



Figure 36. Individual 6 on Day Seven with point of entry stretched to allow for easier access to gluteal muscle. Note skin slip on left lateral abdominal region used as leverage for muscle extraction (Courtesy of FAC).

Individual 7:

The first day of scavenging on this individual occurred 17 days after late fall placement. The first evidence of raccoon activity was scratches on the right scapular region, but no points of entry were observed, and no oviposition was present on the remains. On Day 2 of scavenging the right ear was scavenged, and the left lower and upper arm was scavenged extensively resulting in bone exposure (Figure 37). By Day 3, the arm was completely skeletal with a strand of skin left that still attached the wrist to the shoulder girdle (Figure 38), and the right side of the face exhibited bone exposure (due to scavenging not insect activity) (Figure 39). Throughout the ten days depicted on the body diagram there were six points of entry on both arms and legs in addition to the facial trauma. By Day 10, the skull was more than half exposed although the hair remained intact on the left side of the skull. All limbs exhibited either bone or skin and bone exposure, did not enter bloat, and had no oviposition or maggot activity. Observer 1 ADD (340.41) underestimated PMI. Actual ADD was 390.10 and PMI was 50 days.

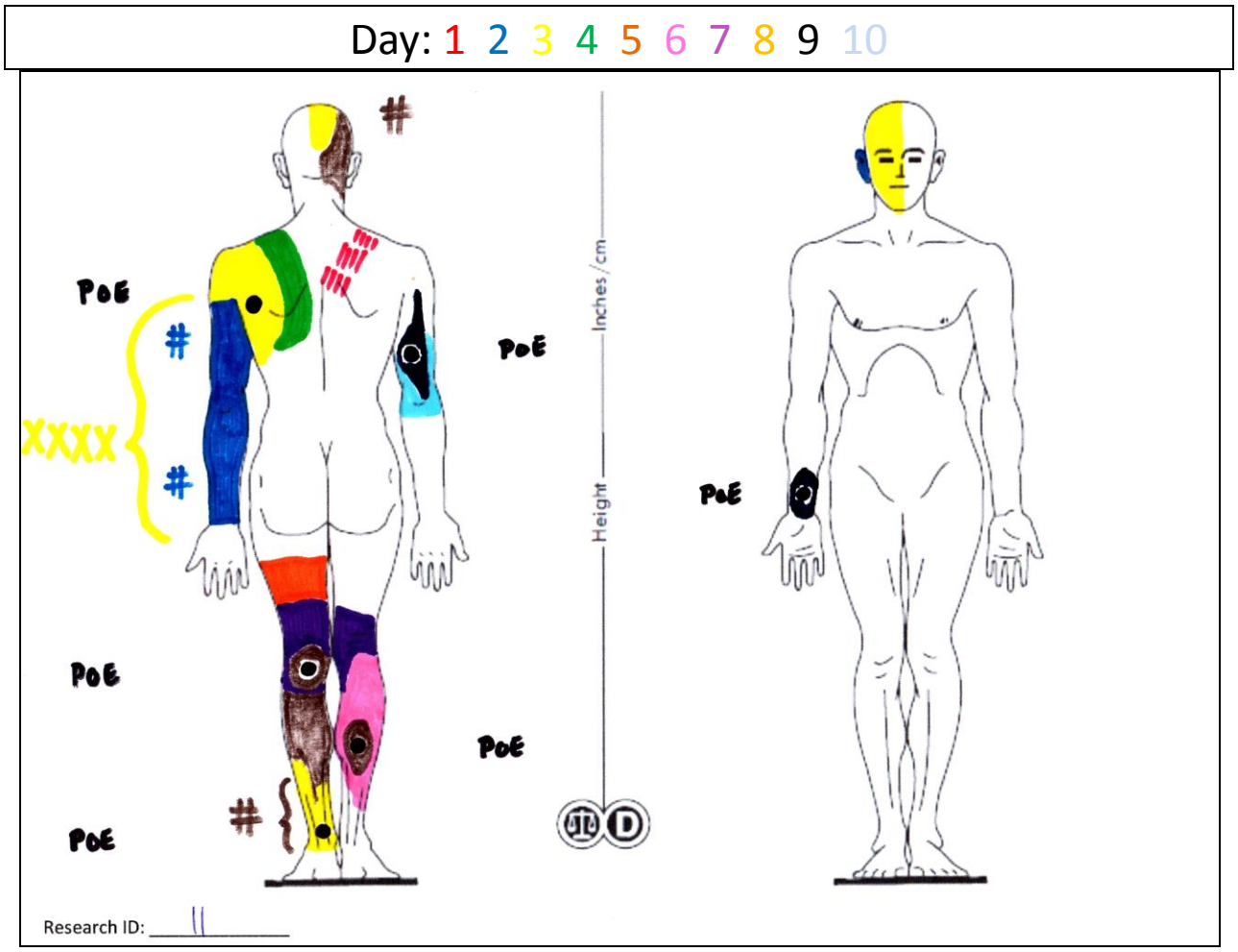


Figure 37. Individual 7 scavenged for ten days.



Figure 38. Individual 11 with skeletonization of left arm on Day Three (Courtesy of FAC).



Figure 39. Individual 7 with scavenging on face exposing bone on Day Three (Courtesy of FAC).

Individual 8:

Scavenging occurred 30 days after winter placement. The initial places of scavenging were on the right side of the face with bone exposure and on the posterior portion of the left arm near the elbow (Figure 40). On Day 2 a POE was noted on the palmar surface of the right hand with scavenging on the forearm, resulting in bone exposure, and on the upper arm. By Day 5 the right arm was completely skeletal. As scavenging progressed, the right upper and lower leg were hollowed and deflated with the extraction occurring on the upper leg up into the gluteal region. On Day 8 a testicle was removed and left on top of the black plastic sheeting that covered the remains although the penis remained intact; and more gluteal musculature was extracted

crossing from the right buttock to the left gluteal region until both buttocks and the left upper thigh were hollowed out and deflated by Day 10. Although not depicted on the body diagram, scavenging occurred for 24 days, continuing down the left leg distally until the leg was skeletal, with the same occurring on the left arm. No insect activity was noted on the remains during this time. Observer 1 ADD (340.41) overestimated PMI. The actual ADD was 232.1 and PMI was 42 days.

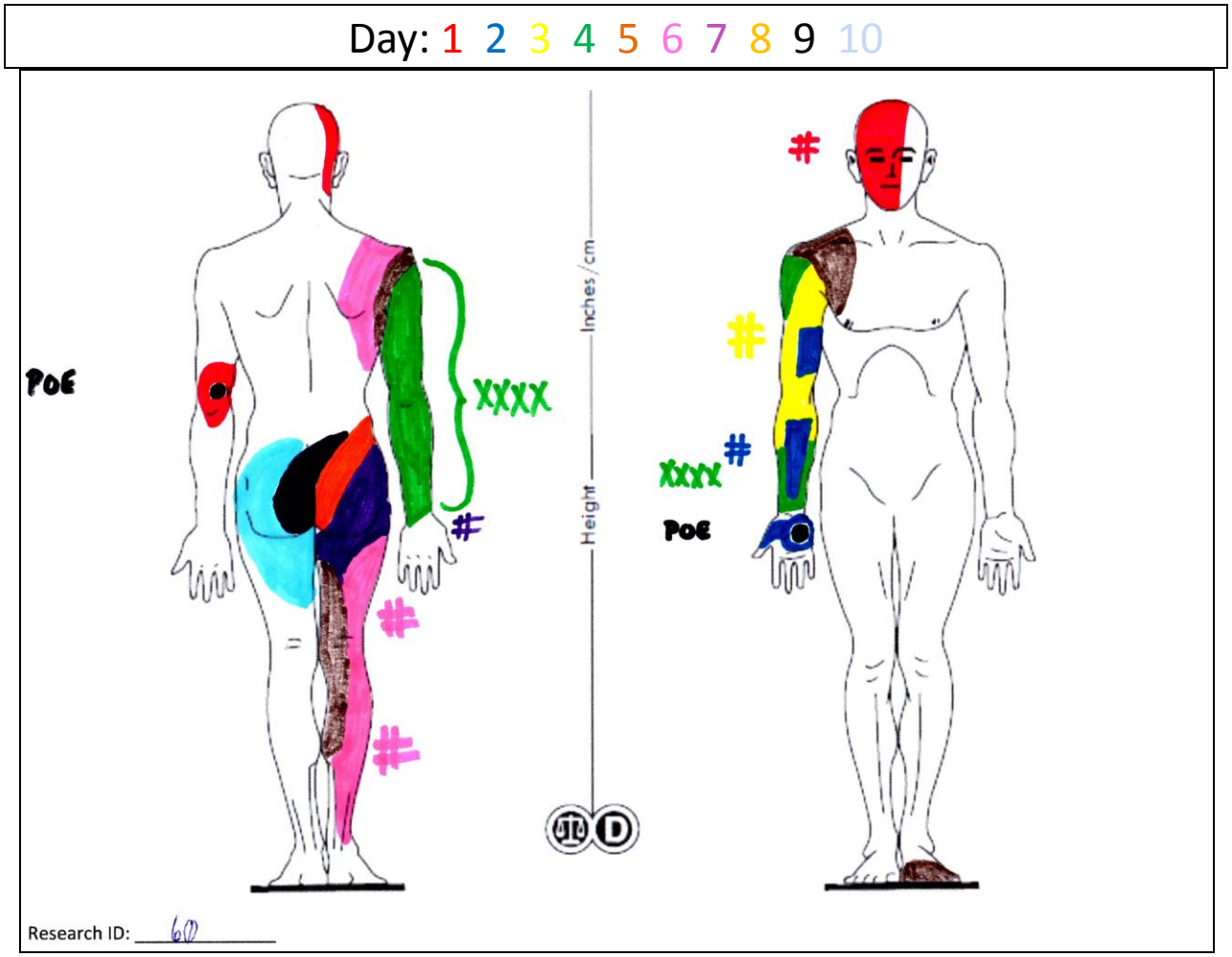


Figure 40. Individual 8 scavenged for a total of 24 days.

Individual 9:

Placed in the winter, this individual was not scavenged until 18 days after placement (Figure 41). No oviposition or insect activity was noted at scavenging onset or completion. The initial POE was in the right posterior shoulder region at the shoulder joint and continued for ten days with each day resulting in more muscle extraction from the same POE. As a result, hollowing and deflation occurred in the deltoid, trapezius,

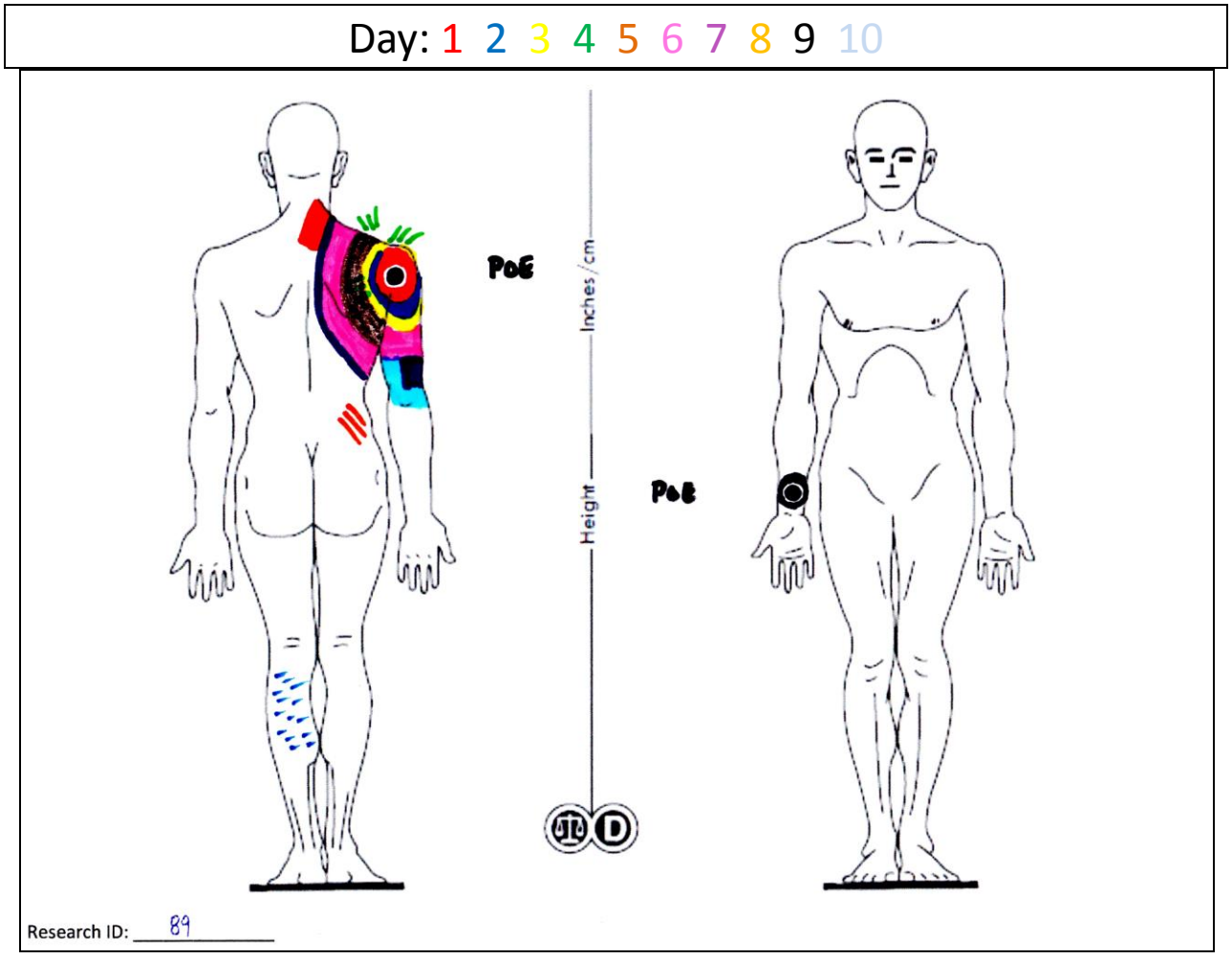


Figure 41. Individual 9 scavenged for 35+ days.

and latissimus dorsi muscle regions although the truck remained relatively fresh with some darker red-to-purple discoloration; no skin slip was evident. This individual was also autopsied, but no disturbance of the thoracic or abdominal cavity was visible; and scavenging occurred for greater than 35 days. The Observer 1 ADD of 93.76 underestimated PMI. Actual ADD was 165.93 and PMI was 29 days.

Individual 10:

This individual was placed in the spring; however, scavenging did not occur until 23 days after placement. At scavenging onset, there was very light oviposition and maggot activity on the head, back, and buttocks. Scavenging commenced on the right hand and continued up the arm with bone exposure by Day 3 (Figure 42). Again, scavenging continued in the right scapular region, hollowing out and deflating the deltoid, trapezius, and latissimus dorsi regions. The right leg was also scavenged with a POE at the medial aspect of the knee extending down towards the ankle by Day 8, and just below the buttock by Day 10. Scavenging continued for 27 days on the lower extremities until they were skeletal, however, maggot activity and their byproducts inhibited further activity on the upper limbs. Observer 1 ADD of 181.97 was well under the actual ADD 510.14 underestimating PMI. Actual PMI was 34 days.

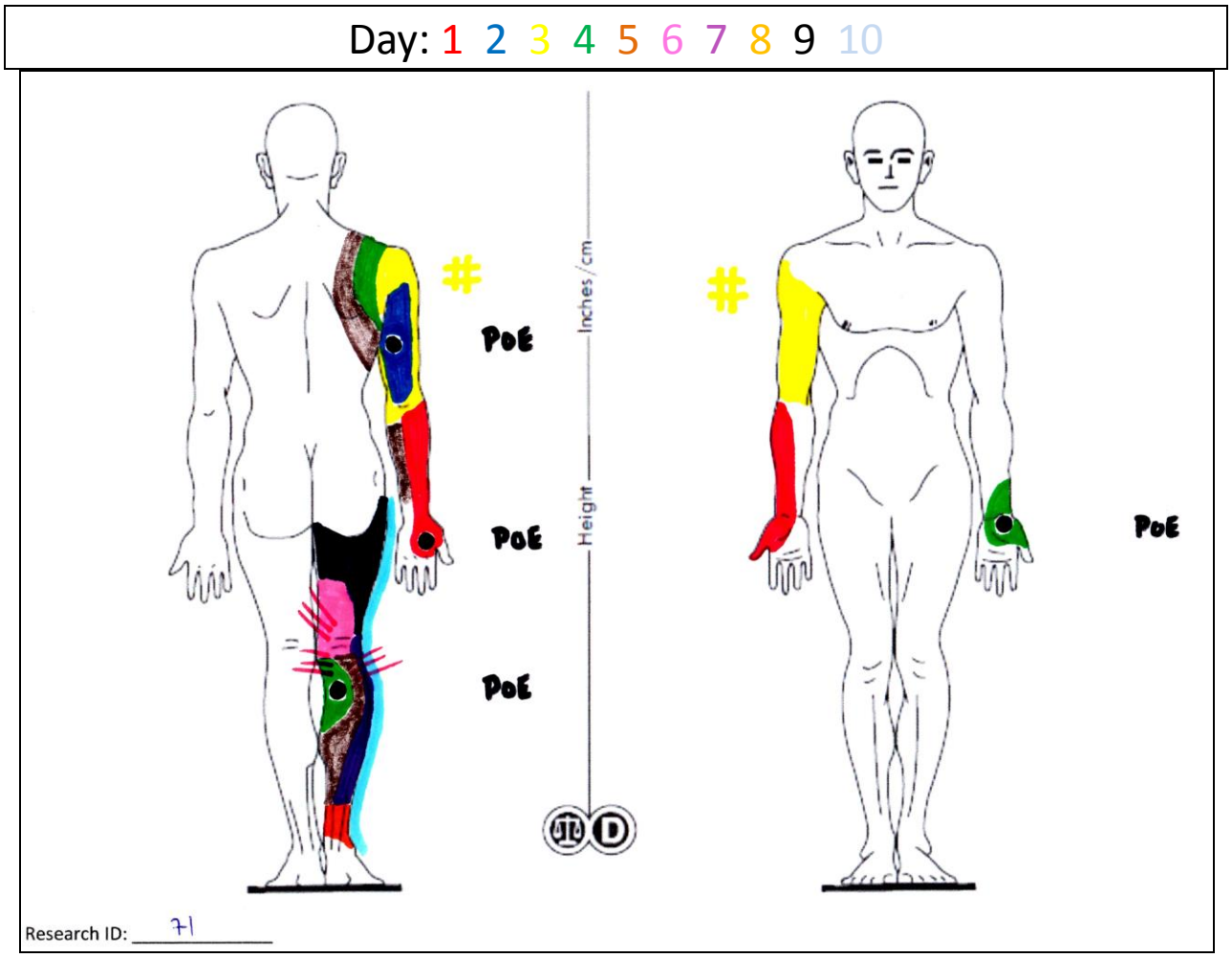


Figure 42. Individual 10 scavenged for 27 days.

Visual representation of PMI Estimation

The results of Observer 1 ADD scores in this research were then compared to estimated PMI, actual ADD, and actual PMI (Table 7). The graphs depict the comparison of actual ADD to Observer 1 ADD (Figure 43), in addition to comparisons with Observer 2 low and high ADD (Figures 44 and 45). This visual representation demonstrates the accuracy of ADD calculations across the sample size, and allows for

further investigation into variables that could affect PMI estimation (e.g. scavenging, season of deposition, stage of decomposition, insect activity, etc.).

Table 7. Results of Estimated to Actual PMI

Individual	*Observer 1 ADD*	*Observer 1 Estimated PMI (in days)*	*Actual Accumulated Degree Days*	*Actual PMI (in days)*	*Difference*
1	**209.89**	**12**	**402.29**	**24**	**Under**
2	**112.72**	**3**	**112.71**	**3**	**Equal**
3	**287.08**	**11.5**	**185.89**	**6**	**Over**
4	**112.72**	**3.5**	**107.54**	**3**	**Equal**
5	**125.31**	**4.5**	**107.62**	**3**	**Over**
6	**140.60**	**14**	**227.07**	**23**	**Under**
7	**340.41**	**44**	**390.10**	**50**	**Under**
8	**340.41**	**54**	**232.10**	**42**	**Over**
9	**93.76**	**15**	**165.93**	**29**	**Under**
10	**181.97**	**12**	**510.14**	**34**	**Under**

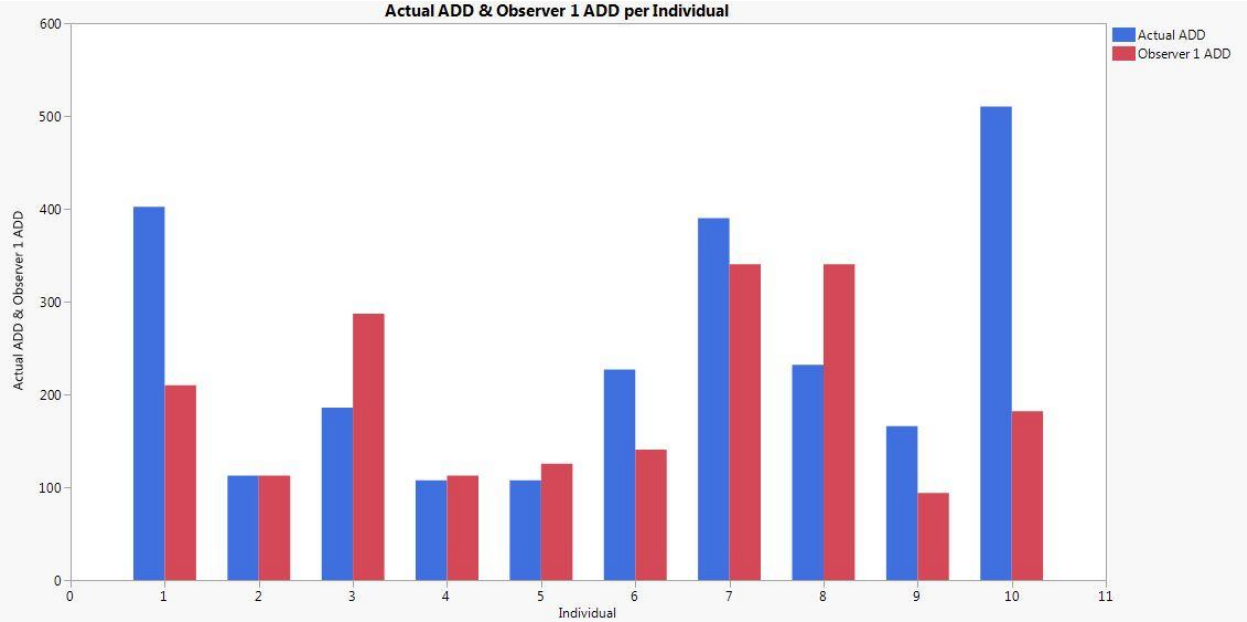


Figure 43. Actual accumulated degree-days compared to Observer 1 ADD scores set forth by Megyesi et al. (2005).

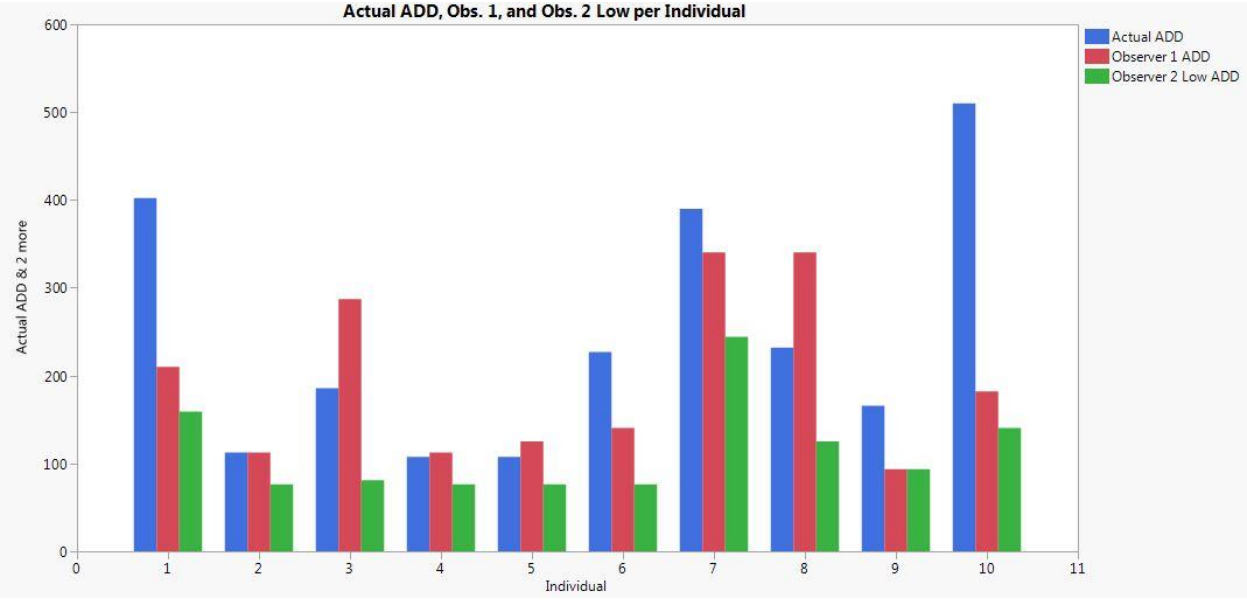


Figure 44. Actual accumulated degree-days compared with Observer 1 ADD scores and Observer 2 low ADD scores.

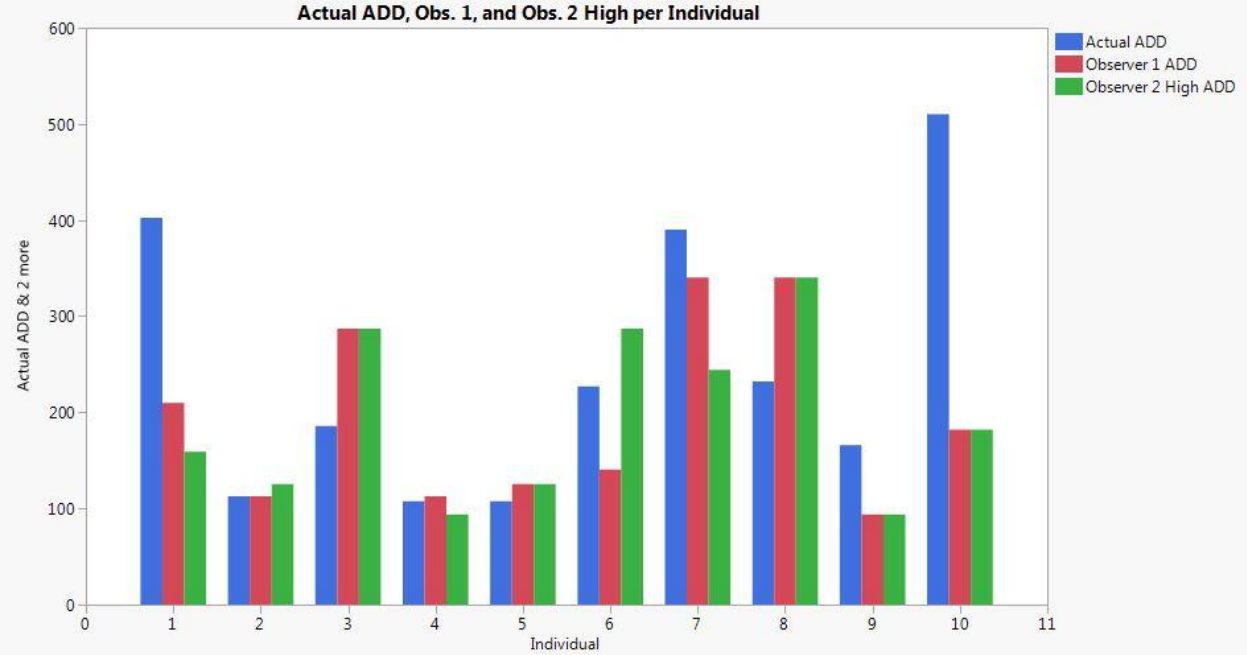


Figure 45. Actual accumulated degree-days compared with Observer 1 ADD scores and Observer 2 high ADD scores.

Statistical Significance

The actual ADD and Observer 1 ADD scores were subjected to a paired samples, two-tailed t-test. These sample means are not significantly different (t = 0.92; p = 0.37). These calculations were then subjected to a Pearson's product moment correlation. The correlation between the two variables is moderate (r = 0.44) and is not significant (p = 0.21). Secondly, a two-tailed t-test was run for Observer 1 ADD and Observer 2 low ADD scores and the datasets are significantly different (t = 2.28; p = 0.04). Pearson's correlation shows a moderate-to-strong correlation (r = 0.65) that is significant at p = 0.04. Lastly, are comparisons between Observer 1 ADD and Observer 2 high ADD scores. The paired samples, two-tailed t-test shows no significant difference between the Observer 1 and Observer 2 high means (t = 0.016; p = 0.99). The

Pearson's product moment correlation shows a strong correlation between ADD values ($r = 0.78$) that is significant at $p = 0.007$ (M. Kenyhercz, pers. comm.). The correlation indicates that the strongest agreement among observers is incurred when Observer 2 uses the high score instead of the low score (Tables 8 and 9).

Table 8. Welch Two-tailed t-test (* = significant at < .05).

Comparison	*t*	*df*	*p-value*
Actual ADD vs. Observer 1	**0.9161**	**15.793**	**0.3734**
Observer 1 vs. Observer 2 low score	**2.2782**	**14.32**	**0.03854***
Observer 1 vs. Observer 2 high score	**0.016**	**17.917**	**0.9874**

Table 9. Pearson's Product Moment Correlation (* = significant at < .05).

Comparison	*t*	*df*	*p-value*
Actual ADD vs. Observer 1	**1.3691**	**8**	**0.2082**
Observer 1 vs. Observer 2 low score	**2.4287**	**8**	**0.04128***
Observer 1 vs. Observer 2 high score	**3.5712**	**8**	**0.007281***

CHAPTER VI
DISCUSSION

The focus of this study was to assess raccoon scavenging as a variable to test for accuracy in early decomposition PMI estimation based on the total body scoring method by Megyesi et al. (2005). Differential decomposition on bodies that have been scavenged by raccoons shows that scavenging can alter PMI estimation changing the rate and pattern of decomposition by accelerating skeletonization and/or mummification. When accounting for scavenging, factors affecting the decomposition process in this study are: how soon the onset of scavenging began from time of placement (representing the date of deposition upon the surface in forensic cases); the number of days scavenging continued; and seasonality in combination with temperature where temperature was not a stand-alone factor. Using the total body scoring method presented by Megyesi et al. (2005), comparisons of actual ADD and Observer 1 ADD give insight into correlations between those factors listed above.

While studying the daily photographs, documentation showed that raccoons began to scavenge individuals while in either the “fresh” or “early decomposition” stages as defined by Megyesi et al. (2005). However, because bloating of the abdomen occurs during the early decomposition stage and no scavenging occurred at-or-during the bloat stage, early decomposition in this research was defined as pre-bloat. Pre-bloat includes slight skin slippage, some discoloration, and light-to-moderate oviposition or maggot activity with some, all, or none occurring simultaneously. Though each of these descriptions may sound subjective, it is important to remember that the raccoons groom themselves and each other; therefore, will limit themselves to fresher and cleaner food resources. Additionally, if raccoons are in competition for resources with decomposers

and microbes, this may explain why raccoon activity ceases before the bloat stage when both insect activity and microbial activity are at their peak.

The bloat stage was the stopping point for raccoon scavenging on soft tissue, more specifically muscle, and the number of days scavenging occurs before bloat does affect PMI estimation. Season impacts the length of time a body may be scavenged as a body in warmer temperatures will bloat before a body in cooler temperatures or where temperatures fluctuate drastically between daily highs and lows--to put it in more explicit terms, colder meat resources stay fresher longer. This would explain the longer duration of scavenging in the winter months, shorter duration of scavenging in the summer months, and the increased differences in ADD calculations for spring months (i.e. cooler temperatures at night slow down the decompositional processes that occur during the day and allow the body to stay fresher for longer periods of time in comparison to consistently warm temperatures).

Actual ADD and Observer 1 ADD

Four of the ten individuals were placed in the summer months (Individuals 2, 3, 4, and 5). In Figure 46 comparing actual ADD to Observer 1 ADD, three of the four (Individuals 2, 4, and 5) show very similar if not equal ADD calculations for PMI. When comparing the body diagrams for those individuals, scavenging occurred for one, two, and three days, respectively. With each of these individuals scavenging occurred within two days of placement, and they were scavenged no more than three days before entering the bloat stage then scavenging ceased. These results suggest that the less

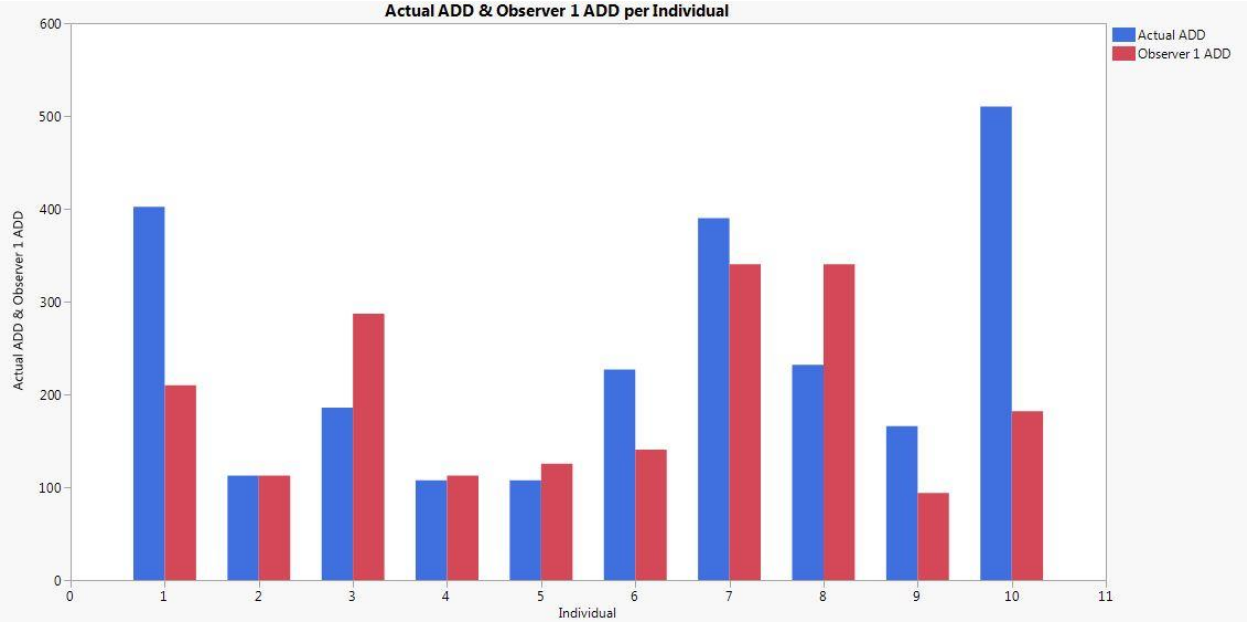


Figure 46. Actual accumulated degree-days compared to Observer 1 scores set forth by Megyesi et al. (2005).

scavenging throughout early decomposition, the more accurate the PMI estimation is using total body scores and ADD calculations. When comparing the three individuals with the fourth placed in the summer (Individual 2, 4, and 5 to Individual 3), extensive scavenging of the limbs occurred increasing the number of access points for maggot activity. Although Individuals 2, 4, and 5 entered bloat, the extensive scavenging and maggot mass activity on the remains inhibited the bloat stage from occurring on Individual 3. This is an important point to highlight because, depending on experience, the stages of decomposition presented by Megyesi et al. (2005) may be interpreted as if they occur sequentially although they can occur simultaneously. Therefore, if bone exposure is present in the summer months before bloat occurs, maggot activity can cause the remains to appear post-bloat due to increased access and additional points of

entry to internal soft tissue. It is important to note that the bloat stage did not occur in Individual 3 due to extensive scavenging and maggot activity. In addition, it was also either delayed or did not occur in the those individuals placed in fall and winter months due to lower ambient temperatures. Individual 3 exhibited extensive scavenging, and it is important to identify and document such scavenging while the individual is in situ since PMI estimations can be drastically affected.

Early decomposition was affected by the amount of scavenging occurring on each individual, and this was contingent on the amount of bone exposure and loss of muscle tissue. Additional points of entry affected soft tissue moisture content by allowing for greater-than-normal surface evaporation of the skin internally and externally. Unless complete skeletonization occurred, limbs where points of entry were repetitively stretched and used to extract muscle became mummified as air flow continued to desiccate the remaining soft tissue.

In regards to the stages of early decomposition, it is important to describe how maggot activity can affect the total body scores presented by Megyesi et al. (2005). Little-to-no oviposition or maggot activity was present on any individuals at the onset of scavenging. However, as scavenging progressed, more access points were created for oviposition to occur. Megyesi et al. (2005) describe purging of decompositional fluids from the eyes, nose, and mouth as one of the stages of early decomposition; however, purge may not always occur or be noticeable if maggot masses have created their own frothy and/or liquid byproduct. Body positioning may also complicate any observances of purge throughout the process of early decomposition due to maggot activity,

especially in instances where the individual is placed prone. In addition, skeletonization of the face may be caused from either scavenging or extensive maggot activity not strictly as a result of temperature.

Scavenging occurred on each individual before major oviposition or larval growth. However, whether oviposition, larval growth, or maggot activity were light or nonexistent at the onset of scavenging, after scavenging they either began or continued to consume what tissue remained in scavenged and non-scavenged areas. The scavenged areas were severely dehydrated due to increased internal surface evaporation. Those areas also appeared mummified and were hollowed out and deflated although the skin remained intact. Maggot infestations invaded the new openings in the tissue, and the masses moved from the distal ends of the openings more proximally as they consumed the remaining dermal layers while migrating towards the torso. Therefore, reinfestation can occur after scavenging, and can obscure soft tissue damage caused by scavengers.

Individuals 1, 6, 7, 8, 9, and 10 were placed in cooler months (spring, fall, and winter) and the onset of scavenging during those months ranged from six to thirty days. When comparing Individuals 1 and 10, actual ADD was well over that of Observer 1 Scores suggesting both individuals were deposited outdoors for half the amount of time than they actually were, drastically underestimating the PMI. Cooler temperatures correlate with greater and longer preservation due to the decrease or absence of insect activity that is present in warm months thereby providing raccoons with fresher muscle and sources of protein for longer periods of time. Scavenging was extensive and longer

in duration during the cooler months, and each scavenged limb showed progressively more intense reuse and consumption.

Observer 1 ADD Compared with Observer 2 Low and High ADD

In addition to calculating total body scores to test for accuracy of Observer 1 ADD scores against actual ADD, interobserver total body scores were calculated as well to test for subjectivity in PMI estimations. Comparison of Observer 2 low scores, which the scorer believed to be the score Megyesi et al. (2005) would have used, to actual ADD all total body scores underestimated the actual PMI. All Observer 2 low scores were below those of Observer 1 ADD scores as well. This suggests that scavenging especially in terms of the acceleration to skeletonization creates a variable that must be considered when attempting total body scoring and PMI estimation. When comparing actual ADD to Observer 2 high scores, half of the scores overestimated PMI. The remaining five individuals had scores that were either significantly lower or just below actual ADD. Individuals 1 and 10, who were placed in spring, showed the greatest differences in both Observer 2 low and Observer 2 high ADD scores when compared to actual ADD. Observer 2 low scores demonstrate how forensic investigators without much experience in decomposition may calculate total body scores for PMI estimation strictly following the rules set by Megyesi et al. (2005). The Observer 2 high scores depict scores that may be determined by those with more experience in ante, peri, and postmortem variables, including specific scavenging signatures.

CHAPTER VII
CONCLUSION AND RECOMMENDATIONS

Temperature and entomology use have been the gold standard when attempting to estimate PMI; however, it is important that other variables are considered and understood in order to incorporate those variables into quantitative methodologies. Consideration of scavenging as a variable must take at least three key factors into account: recognition, awareness, and interpretation (RAI). Firstly, it is important to recognize that scavenging has occurred and that deterioration of the remains is not strictly due to the natural process of decomposition. Secondly, it is important to be aware of scavengers and their particular “signatures” because their activity compromises the “normal” decomposition process. Third, accuracy in the application and interpretation of scavenging is necessary to adjust for changes in the typical process of PMI estimation.

Scavenging on soft tissue presents variables that must be considered in order to effectively and accurately estimate PMI. Scavenging by various species and their taphonomic affects have been documented in the literature, yet, the information needs to be accessible to forensic investigators and then applied for use towards PMI estimation. Raccoon scavenging, specifically, can affect PMI estimation during early decompositional stages changing both the rate and pattern of decomposition (Jeong et al. in press). The creation of additional access points allows for greater maggot infestation earlier in the decomposition process. The length of time scavenged along with increased maggot activity can accelerate mummification, skeletonization, and mimic an individual in post-bloat when in actuality the individual may have never entered the bloat stage.

Further research is needed to better quantify how scavenging may affect total body scores and PMI estimation. With the continual advancements in technology, it may be possible to apply geographic information system (GIS) approaches creating maps of scavenged areas on the individual that would be more representative muscle loss and how it affects the acceleration of mummification than those diagrams included here (M. Kenyhercz, pers. comm.). In addition to providing for better visual representation of scavenging and its effects on decomposition, creating formulae that would adjust for or incorporate scavenging and insect activity would be useful for ADD calculations to allow for greater accuracy in PMI estimation. Refining total body scoring systems and point values that would include adjustments for variables other than temperature would aid in this as well. For example, if the body was wrapped, was it wrapped in cotton that would accelerate mummification due to the dehydrating effects of the material, or was it wrapped in plastic that prolongs the moist decomposition stage? (Dautartas 2009). The same could be done with scavenging and many other variables using the RAI approach above. Outdoor research facilities dedicated to the study of human decomposition are becoming more prominent in the U.S. and from these research facilites, greater understanding of the many variables and their effects on the decomposition process can be applied to forensic investigations both regionally and nationally.

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