ABSTRACT

Lisa Leone. A STUDY OF DECOMPOSITION RATES IN EASTERN NORTH CAROLINA (Under the direction of Dr. Megan A. Perry) Department of Anthropology, July 2006.

Estimating the time since death (or postmortem interval) via postmortem changes is crucial in forensic cases involving decomposed human corpses. Several factors can influence the rate of decomposition, such as ambient temperature, rainfall, and humidity. Decomposition rates thus can vary drastically between two locations because many factors are environment specific. Taphonomic and entomological information need to be studied at the local level. The present study observed the decomposition of two domestic pigs (*Sus scrofa*) of 103 and 158 pounds in weight. After being humanely killed, these specimens were placed on the soil surface in two contrasting environments on East Carolina University's West Research Campus. One specimen was placed in a cooler, shaded area, while the other was placed in direct sunlight. From August 2005 to January 2006, data were gathered on the temperature, rainfall, and humidity experienced at each site. The weight (biomass) loss, girth, and insect activity occurring with each pig specimen was also recorded.

The purpose of this case study was to investigate decomposition rates in eastern North Carolina and to determine which environmental factor(s) most influenced this process. First, subjects placed in different environments were expected to decay at different rates. Second, the shaded and exposed subjects additionally were expected to follow the same basic decomposition patterns as those seen in Shean et al.'s (1993) meaning that the exposed subject would reach maximum bloat before the shaded subject and also decompose at a more rapid rate. First, ambient temperatures profoundly influenced insect activity, the primary mode of biomass loss, as did the amount of sunlight exposure and the direct relationship between exposure to sunlight and moisture. Second, the exposed subject did achieve maximum bloat before the shaded subject (49.0 inches by day 2 versus 41.0 inches on day 3). However, the exposed pig did not decompose before the shaded pig. The exposed pig first lost a higher percentage of biomass per day than the shaded pig (43% versus 17.5 %) primarily as a result of warmer temperatures experienced at the exposed site. Prolonged exposure to high temperatures and direct sunlight however caused the soft tissues of the exposed subject to dehydrate and become unsuitable for insect use and decomposition thus slowed as fewer and fewer insects frequented the exposed carcass.

A STUDY OF DECOMPOSITION RATES IN EASTERN NORTH CAROLINA

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A STUDY OF DECOMPOSITION RATES IN EASTERN NORTH CAROLINA

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CHAPTER ONE

INTRODUCTION

Determining the time since death (postmortem interval or PMI) of a human corpse is a necessary part of death investigations (Campobasso et al. 2001; Mann et al. 1990; Rhine and Dawson 1998; Rodriguez and Bass 1983). Effectively estimating the postmortem interval requires knowledge of the local factors that influence decomposition processes.In response to this need, numerous decomposition studies have been conducted at various sites around the world to acquire regionally specialized data. These investigations have utilized test subjects ranging from dogs (Reed 1958), toads (Cornaby 1974), (Payne 1965; Hewadikaram and Goff 1991; Shean et al. 1993; Avila and Goff 1998; Lopes de Carvalho and Linhares 2001), and in ideal situations, humans (Bass 1997; Clark et al. 1997; Galloway et al. 1989; Mann et al. 1990; Rodriguez 1997; Rodriguez and Bass 1985). The results from these investigations have indicated that micro-level studies are necessary to truly assess PMI.

The decomposition process begins immediately following the death of an individual but the rate that this occurs and the stages that it involves vary due to numerous intrinsic and extrinsic factors. All of the factors that influence the rate of soft tissue destruction therefore must be accounted for when calculating the postmortem interval. Influential factors include temperature, precipitation, humidity, and access to the corpse by insects; all of which vary by region. Local investigations into the rate of decomposition thus provide an important component to forensic investigations relying on accurate PMI estimates. Building upon previous research, this study examines decomposition rates in eastern North Carolina.

The present study observed the decomposition of two domestic pigs (*Sus scrofa*) to investigate decomposition rates in two contrasting environments on East Carolina University's West Research Campus. One specimen was placed in a relatively cool, shaded area, while the other was placed in direct sunlight. From August 2005 to January 2006, data were gathered on the temperature, rainfall, and humidity experienced at each site. The weight (biomass) loss, girth, and insect activity occurring with each pig specimen were also recorded.

The results of this study should show that subjects placed in different environments (shaded versus exposed) experience different rates of decay based on previous studies by other researchers. It is also expected that each subject will follow the same basic decomposition patterns observed in other research (Shean et al.1993) due to their unique environment. The carcass exposed to the sun will reach maximum bloat and decompose sooner than the shaded subject. These expectations are based on the impact of temperature and insect activity on the decomposition process.

The following chapters explain the details of this case study further. Chapter two will outline previous research undertaken to quantify PMI in different environments and discusses the generation of this research project. This will be followed by a discussion of the expected results based on previous research, and the materials and methods employed in this investigation. The results will be discussed in chapter four and placed within the context of other research in chapter five. Chapter five will additionally detail the implications of the research for PMI estimation.

CHAPTER TWO

BACKGROUND

As noted in the introduction, estimating PMI via postmortem changes in the corpse is crucial in forensic cases involving decomposing or decomposed human corpses (Campobasso et al. 2001; Mann et al. 990; Rhine and Dawson 1998; Rodriguez and Bass 1983). Determining the time since death interval allows investigators to confirm, for instance, the identity of the deceased individual based on the time of their disappearance (Bass 1997; Rhine and Dawson 1998) and the culpability of a possible perpetrator. Trying to establish the PMI necessitates a working knowledge of decomposition rates and the local influencing factors. The following chapter will detail the importance of studying decomposition rates at a local level and will survey previous research on decomposition using both human and nonhuman test subjects. In addition, the literature on forensic entomology and decay rates is examined.

Local Decomposition Studies

Several factors can accelerate or inhibit the rate of decomposition. Such variables include ambient temperature, humidity, rainfall, depth of burial, and presence/absence of clothing (Mann et al. 1990). Decomposition rates can vary drastically between two locations (or microenvironments) because the climatological factors that influence the rates are environment-specific. Shean et al. (1993) for example noted the variation of whether across small distances; they recorded rain at their study sites on five days, the Olympia airport's weather station located six miles away recorded rain on only two of those days. Researchers have conducted decomposition studies in several geographic regions across the country, yet taphonomic and entomological information derived from

these studies is not applicable to all locations, nor have the data identified universal constants for determining the postmortem interval in any given situation. Several researchers thus declare the need for study of decomposition rates at a local level (Galloway 1997; Manhein 1997; Mann et al. 1990). In response, localized data on decomposition rates have been studied to provide a better understanding of the decomposition processes that would be expected in eastern North Carolina and estimate the postmortem interval of local corpses.

The Process of Decomposition

In addition to insect visitation, several events, both macroscopic and microscopic, that take place immediately following the death of an individual can be used for PMI estimation. The macro level includes the processes of algor, livor, and rigor mortis. Algor mortis is the cooling of the body after death the rate of which (approximately 1.5 degrees F per hour) can be used as an indication of PMI (Dix and Graham 2000). Algor mortis however is only reliable up to 24 hours after death. Another process occurs after the heart has stopped pumping blood throughout the body, gravity causes the blood to pool or settle into the lowest parts of the body. This process and subsequent purple discoloration is known as livor mortis or lividity. Lividity becomes fixed at approximately eight to ten hours after death, and thus can be used as a tool in estimating the PMI of an individual, but only up to the time it becomes fixed (Dix and Graham 2000; Merkeley 1957). Rigor mortis, rigidity or contraction of muscles, also begins within hours after death. This rigidity results from an abundance of lactic acid resulting from the chemical breakdown of adensosine triphosphate (ATP) in the muscles. This postmortem change can also be used to determine PMI as it occurs and dissipates at a known interval: begins one to three

hours after death and dispels 24 to 36 hours after death. It is not known to be a useful indicator of time since death after 36 hours (Merkeley 1957; Dix and Graham 2000).

After death, the process of soft tissue destruction begins as a result of two agents: autolysis and putrefaction. Autolysis simply refers to the breakdown of cells by the enzymes within them (Dix and Graham 2000). No bacteria are involved in autolysis. Putrefaction also begins immediately after death and is caused by the activity of both enzymes and anaerobic bacteria in the gut (Dix and Graham 2000). After death, aerobic microorganisms consume the available oxygen left in the intestines, which makes the conditions more favorable for anaerobic species of bacteria to proliferate and digest tissues (Merkeley 1975; Dix and Graham 2000). Bacteria similarly play a role in late-stage decompositional changes. Bacteria create gases (predominantly methane) that produce the bloating and swelling associated with early decomposition. Marbling of the skin also occurs when degenerated blood reacts with the hydrogen sulfide produced by the proliferating bacteria. Blood within vessels near the skin's surface become stained black and give the skin a marbled appearance (Dix and Graham 2000).

The process of decomposition is continual and progressive and cannot be easily broken up into discrete and separate stages. At the same time, researchers continue to discuss decomposition in terms of such stages because they act as a set of standard criteria that facilitate comparison between studies and cases. Researchers have formulated their own series of decomposition stages based on categories that most accurately reflect the sequence of tissue destruction that result form the unique environment in their study area (Galloway et al. 1989; Goff 2000; Reed 1958).

Galloway and colleagues (1989) for example derived a series of decay stages based on data gathered from the arid environment of Arizona. Fresh, early decomposition, advanced decomposition, skeletonization, and decomposition of skeletal material are the 5 categories that best reflect the patterns seen in their area. Galloway et al. correlate the first 4 stages with those of Rodriguez and Bass (1983), who derived their stages from Reed (1958). A *fresh* body contains no insect activity or discoloration according to their classification. Discoloration and bloating signify *early decomposition*. *Advanced decomposition* includes maggot infestation and soft tissue decay to the level of skeletal exposure. Adipocere, a decompositional product consisting of saturated fatty acids (Janaway 1996), and mummification can also occur during this stage. Galloway et al. (1989) consider a body to be *skeletonized* when most of the bones become exposed. *Decomposition of skeletal material* reflects changes, exfoliation and bleaching, seen in the hard tissues of the bone after all soft tissue was removed and the skeletons were exposed to the environment.

In the mid 1980s, Goff (2000) and two graduate students divided the process of corpse destruction in tropical habitats into 5 stages: fresh, bloated, decay, post-decay, and skeletal. Goff's *fresh stage* begins at death and ends with the onset of bloating. The onset of bloating marks the start of the *bloated stage*, which Goff admits is "hard to determine precisely" (Goff 2000: 44). The bloated stage ends with the deflation of the corpse, caused by the release of internal gases from natural orifices and holes in the carcass made by feeding insects. The *decay stage* begins with the deflation of the corpse, although its endpoint is less well-defined. Goff considers the decay stage to be complete when 20 percent or less of the corpse's original biomass remains. Soft tissue destruction continues

until 10 percent or less of the biomass remains, which signifies the end of the *post-decay stage*. At this point only bones and hair remain. The corpse would now be considered as within Goff's *skeletal stage*.

Previous Research

Numerous decomposition studies have been conducted at various sites and have employed a number of different animals as test subjects. Researchers have utilized dogs (Reed 1958), lizards and toads (Cornaby 1974), rats (Micozzi 1986), pigs (Payne 1965; Hewadikaram and Goff 1991; Shean et al. 1993; Avila and Goff 1998; Lopes de Carvalho and Linhares 2001), and even humans (Bass 1997; Clark et al. 1997; Galloway et al. 1989; Mann et al. 1990; Rodriguez 1997; Rodriguez and Bass 1985). These studies have discovered the variables that affect decomposition rates in addition to the applicability of these results to understanding human decomposition.

Reed's (1958) early study of dog carcasses in east Tennessee compared insects that visited carcasses placed in wooded areas versus those in pasture (or non-wooded) areas. He spaced the carcasses far enough apart so as not to impose competition for arthropod visitation between carcasses. Wire cages were constructed around the dog carcasses to protect them from large scavengers. These cages however had neither bottoms nor auxiliary protective enclosures. Scavengers dug beneath the wire and occasionally were able to access the carcasses. This is problematic because scavengers can remove large portions of a carcass which will skew the rate of biomass loss influenced by environmental factors. Dogs additionally are not the ideal creature for simulating human decomposition. First, dogs are covered with a heavy coat of fur, very much unlike humans. Mann, Bass and Meadows (1990) feel that dog carcasses decay too

rapidly and thus cannot support arthropods for a long as human corpses can. Nonetheless, Reed was able to conclude that insect activity (and thus decomposition) proceeded at an accelerated pace in the pasture areas as compared to the wooded areas (Reed 1958). Such results are consistent with other studies of carcasses in shaded (wooded) areas versus unshaded (pasture) areas in which the higher temperatures reached in the unshaded areas facilitated faster decomposition rates (Shean et al. 1993; Lopes de Carvalho and Linhares 2001; and Rodriguez and Bass 1983).

Reed (1958) determined that his canine subjects underwent four stages of decomposition: fresh, bloated, decay, and dry. The *fresh* stage began at death and lasted until bloating of the carcass began. From early bloating to deflation of the carcass signified the *bloated* stage. The *decay* stage commenced with the deflation of the carcass and was characterized by the decay of the soft tissues and the breaking open of the skin. Reed (1958) noted that the *dry* stage had limits that were difficult to define. During this stage small amounts of tissue may still remain and the carcass can still be considered as "dry" even if it is moist from rain or dew. By this point in the decomposition process no carrion insects remain at the carcass.

Later studies focused on the effects of other environmental and climatic variables on decomposition rates. In 1974, Cornaby (1974) placed a number of lizards and toads in dry and wet tropical forests in Costa Rica and observed their decay. Cornaby determined from his observations that ants were important reducers of the soft tissues. Corpses in the wet tropical forest versus the dry tropical forest additionally accelerated decomposition. The latter observation has implications for the influence of precipitation and climate on the rate of carcass decay.

In Philadelphia, Pennsylvania, female rats were used as test subjects in 1980 by Micozzi (1986) to investigate the consequences on decomposition and skeletal disarticulation by freezing and thawing. The act of freezing and subsequent thawing of the rat carcasses was intended to simulate the postmortem changes occurring in humans who die during the "frost season" (Micozzi 1986: 960). According to Micozzi, the control rats (fresh-killed) seemed to decompose from the "inside-out." Postmortem changes in these subjects were the result of purification by enteric microorganisms. Decay of the treated subjects (frozen-thawed) appeared to occur from the "outside-in." The act of freezing the rat corpses weakened the skin and made it more penetrable by carrion arthropods. Studies like Micozzi's should not be used to determine postmortem intervals, but can provide an example of the various animals that have been utilized in decomposition studies for the benefit of humans. This study also has implications for understanding decomposition rates in winter months.

Researchers prefer to use human subjects in decomposition studies (Bass 1997; Clark et al. 1997; Mann et al. 1990; Rodriguez and Bass 1983). The use of human subjects however is rarely an option for most researchers due to the difficulty of procuring cadavers and the need for secure locations to place the body for observation (Mann et al. 1990). Some researchers have been able to conduct human decomposition studies with cadavers, mostly in association with the University of Tennessee's Anthropology Research Facility (ARF) or "Body Farm" (Bass 1997; Mann et al. 1990; Rodriguez and Bass 1983). Others have studied decomposition rates retrospectively using a combination of case records and photographs Galloway et al. 1989).

In a 1983 study, Rodriguez and Bass employed 4 donated human cadavers to examine the relationship between arthropods and the decomposition rates of human soft tissues. The corpses were placed within the ARF at various times of the year inside wire mesh coffins to protect them from the scavenging rodents of eastern Tennessee. Rodriguez and Bass observed that the cadavers underwent the 4 stages of decomposition similar to those identified by Reed (1958): fresh, bloated, decay, and dry. Other observations included the propensity for a more rapid bloat during periods of warm weather, as well as an increase in number and diversity of arthropods with warm temperatures. This increase of arthropods led to an increased rate of tissue decay, which has implications for the importance of temperature considerations when determining the time since death interval.

In 1990, Mann and colleagues summarized the general influence of certain variables on the decay of humans, seen both in forensic cases they had investigated and in experimental studies they had conducted in east Tennessee. Variables were ranked according to the magnitude of impact on the decomposition process. They reported that temperature, the availability of the body to insects, and whether the body was buried (and if so, its depth) were the most influential factors affecting decomposition rates. Carnivore activity, the presence of trauma, and the humidity of the environment were found to be the next most influential group of factors. The amount of rainfall experienced at the scene and the size/ weight of the body only slightly impacted the rate of decomposition. Most of the above variables are environmentally specific, which implies the gravity of the consequences if the environment is not given adequate attention during an investigation.

Bass (1997) later summarized the results of research conducted at the University of Tennessee's Anthropology Research Facility and his 30 years of forensic experience. According to Bass, ambient temperature most strongly influences the decomposition of human remains. The ideal scenario for quickest decomposition involves leaving the body on the surface, high temperatures (with no direct sunlight), high humidity, and adequate infestation by carrion insects. Bass remarks that when the remains are in direct sunlight, maggots will leave the skin intact in order to use it as protection from the sun. As a result, the skin becomes dehydrated eventually naturally mummifies. Degradation occurs more quickly during the summer months, however the decomposition process continues even during cold seasons, although at a much slower rate (Bass 1997). This is significant for carcass decay being monitored over a period of both warm and cold months.

In Galloway and colleagues' 1989 study, photographs and documentation of 189 forensic cases handles by the Human Identification Laboratory of the Arizona State Museum were examined (Galloway et al. 1989). From data such as the "last-seen-alive" date, date of discovery, and the month in which death was believed to occur, the researchers sought to estimate the PMI of each of the 189 individuals (Galloway et al. 1989: 608). Galloway et al. grouped remains according to 5 categories (fresh, early decomposition, advanced decomposition, skeletonization, and decomposition of skeletal material). The researchers correlated the first four of the above categories with those used by Reed (1958) and Rodriguez and Bass (1983). Galloway et al. noted that insect activity, the main process accelerating decomposition, was greatly influenced by environmental factors such as temperature, sunlight, and moisture. For example, summer decomposition occurred at a faster rate due to the warm temperatures, while winter rates slowed to one-

fifth that during the summer. In this retrospective study, exposed remains experienced rapid bloating, dehydration of soft tissues, and mummification of skin, and it may take as long as 8 months for the mummified skin to decompose and reveal the skeleton. When compared to more humid environments like Tennessee (Rodriguez and Bass 1983), Galloway et al. concluded that the duration of some decay stages was shorter for arid environments, likely due to the effect of dehydrated tissues on insect activity.

Procuring human cadavers often is problematic and researchers thus frequently use domestic pigs for decomposition studies as a proxy for human corpses. The domestic pig *Sus scrofa* is the most widely accepted animal for use for approximating human decay (Goff 2000; Haskell et al. 2001) for two main reasons. First, pigs make good models in human decomposition studies because they have a fat-to-muscle ratio comparable to that of humans. Second, pigs are regarded as biochemically and physiologically analogous to humans. The skin of such an animal also makes it an adequate substitute for humans because it lacks heavy fur (France et al. 1997). Goff (2000) recommends using a pig of at least 50 pounds in order to best approximate human decomposition patterns.

Payne (1965) first utilized pigs as a proxy for humans while comparing decomposition rates between baby pigs that were exposed to insects and those that were protected from insects during the summers of 1962 and 1963. Ten baby pig specimens (ranging from 2.2 to 3.2 pounds in size) were placed in cages that either allowed or denied the access of arthropods. For the specimens exposed to insects, decomposition was found to occur in six distinct stages and take only a matter of days. Alternatively, those specimens protected from insects went through five less definite stages and the decomposition process lasted at least three months. Payne reports in fact that 20 percent

of the protected specimen's original carcass weight remained in a mummified form. He also noted that air temperature strongly influenced the decomposition process by physically impacting the insect activity.

Hewadikaram and Goff (1991) investigated whether or not carcass size influenced the rate of decomposition or insect succession patterns. Two domestic pig carcasses of different sizes (8.4 kg and 15.1 kg) were placed in the semi-arid tropical Diamond Head Crater in Oahu, Hawaii. They placed the carcasses within protective cages spaced 30 m apart. Hewadikaram and Goff observed no difference in the basic pattern of arthropod succession between the two carcasses, although they determined that the larger pig (15.1 kg) decomposed at a greater rate than the smaller pig (8.4 kg). The researchers determined that this resulted from the larger pig attracting and supporting a greater number of flies, which resulted in the presence of more maggots and thus "a more rapid removal of biomass." This conclusion correlates with reports by Rodriguez and Bass (1983) that an increase in the number of insects leads to an increased rate of decay and has implications for decomposition of a larger versus smaller individual.

In 1993, Shean, Messinger, and Papworth published a study on differential decomposition of carcasses placed in the sun and in the shade in Washington State. Two white pigs (*Sus scrofa*) were used in this study weighing 22.7 kg and 20.3 kg. The test subjects were placed within a 2.5 cm mesh wire "casket," which was then placed inside another enclosure also constructed of 2.5 cm mesh wire. Decrease in body mass quantified the decomposition rate for these specimens. The caskets allowed the carcasses to be picked up for weight measurements, while placement within the second enclosure kept large scavengers from gaining access to the decaying bodies. Bloat measurements

were taken as well to better chart the carcass progress through the decomposition process. Researchers found that the pig exposed to direct sunlight decayed in 17 days while the shaded pig took 49 days. Higher temperature experienced in the exposed site (which stimulated maggot growth) and the fact that the exposed pig weighed slightly less that the shaded one attributed to this difference in decomposition rates (Shean et al. 1993). This study, like many others, has a largely entomological focus. Shean et al. recorded enough data on climate, in addition to weight and bloat measurements, that the work can be replicated and the results compared.

Avila and Goff (1998) investigated the effects of burned versus unburned carcasses on carrion insect activity patterns. This study employed two different sites, one semi-arid tropical area inside a dormant volcano crater and one rainforest habitat. At each site, one burned and one unburned (control) pig were placed within wire mesh cages (to protect against large scavengers) 10 meters apart. The researchers found similar rates of decomposition for both carcasses (burnt and control) at the volcano and rainforest sites. However, it was found that the burnt specimens at each site lost biomass at a faster rate than the unburned carcasses. The difference in decomposition rates between the burnt and control specimens could influence the estimated PMI by 24 hours to four days, suggesting the potential for erroneous PMI estimates of burned corpses.

The more recent Brazilian study by Lopes de Carvalho and Linhares (2001) addresses differences in decomposition rates as affected by direct sunlight and shade as well as seasonal insect succession. These researchers used the domestic pig *Sus scrofa* as test subjects to most accurately mimic human decomposition. After placement in protective cages, one carcass was placed in a partially sunlit area and the other in a

shaded area. With a maximum temperature of 80 degrees F during Brazil's warmest month, decomposition at the sunny site took only ten days versus twenty-five days at the shaded site. This has implications of possible site preference of arthropod species.

Postmortem Interval (PMI) Estimation

Estimating PMI via postmortem changes is crucial in forensic cases involving decomposing or decomposed human corpses (Campobasso et al. 2001; Kashyap and Pillay 1986; Mann et al. 1990; Rhine and Dawson 1998; Rodriguez and Bass 1983). A corpse's time since death interval is obtained by deciphering the relationship among entomological data gathered from the scene, knowledge of the decomposition patterns in the region, an understanding of taphonomic processes, and climatological/ environmental statistics of the area since the corpse's date if disappearance. Estimating PMI is a notoriously difficult task because of the interrelatedness and mutability of the above factors. Climate factors for instance greatly influence insect activity on the corpse, which is the primary mode of soft tissue decay. Much has been written on forensic entomology and decomposition patterns (Anderson 1999; Catts and Haskell 1990; Goff 2000; Haskell et al. 1997; Kashyap and Pillay 1986; Wells and LaMotte 2001). Studies of insect life cycles are prevalent in the literature as well as case histories in which such entomological evidence was used in determining the PMI of the victim. Likewise, the gross morphological patterns associated with decomposition have been well-documented (Dix and Graham 2000; Merkeley 1957). Regional decomposition patterns however have received less attention. I will thus briefly survey the entomological literature and take a closer look at regional decomposition patterns and the resulting classificatory stages.

Finally, an example is given in which PMI determination played a major role in the resolution of a death investigation.

Forensic entomology, the study of insects/ arthropods from a legal aspect, is used to estimate a body's PMI (Anderson 1999; Catts and Haskell 1990; Goff 2000; Haskell et al. 1997; Kashyap and Pillay 1986; Wells and LaMotte 2001). The PMI can be determined via the degree of insect development or from the stage of succession. Many forensically important insect species develop at a known rate and have well-documented life cycles (Haskell et al. 1997). Thus, measurements of larval length and weight can be compared to known growth curves to determine the age and degree of development of the species found on the body after death. The body could not have been dead for a shorter period of time than what it took for the larvae to reach a particular age. For instance, if the length and weight of larvae present on the body indicate an age of 2-3 days, the individual must have been dead for at least that long (Anderson 1999; Wells and LaMotte 2001). One ecological community of arthropods will progressively become replaced by another throughout the process of decomposition, a process called succession or successional pattern (Anderson 1999; Catts and Haskell 1990). Such ecological succession occurs on a decomposing body because different stages of decay attract different insect species (Anderson 1999). Maggots for example need moist or soft tissues for feeding and thus are present during early to moderate decomposition stages. Some species like the hide beetle on the other hand prefer to eat dried tissues and show up later in the decomposition process (Goff 2000). Entomologists use the degree of development or the successional stage along with statistics on weather conditions, especially temperature, to determine an individual's PMI. Anderson notes (1999) however, that the

precise moment of death cannot be derived from insect data. It can only be used to determine “the minimum time since death” essentially how long insects have been present on the corpse (Anderson 1999: 304).

Numerous examples exist in the literature relating the role played by PMI determination in death investigations. Most examples are case studies with an entomological focus. Few deal with using gross morphological observations of the corpse as the primary factor in PMI determination. However, one such example, dealing with differential decomposition, is given here. Dix and Graham (2000) detail a case in which a man is found dead on the side of the road on a hot day in August, partially covered by a blanket. Lividity was fixed and no Rigor mortis was present. Maggots infested the head and neck due to a large laceration on the back of the head. The ligature used to strangle the man was still tied about the neck. A suspect, the victim’s estranged business partner, was in custody and had an alibi for the day prior to the victim’s discovery. The postmortem interval as determined by the pathologist would be crucial in exonerating the suspect.

The insects were biased to colonizing the head first due to the blood from the head laceration. At temperatures near 90 degrees F, it would have taken the maggots 10-20 hours to carry out the amount of soft tissue destruction seen at the head. It is also likely that the muscle rigidity that follows death could have occurred and resolved in a similar amount of time at such warm temperatures. Along with evidence derived form the victim’s stomach contents, investigators concluded that he had been dead less than 24 hours. It is unlikely the suspect strangled the man since he had a strong alibi for the day before the victim’s discovery.

Estimating the PMI of human corpses thus forms an essential step in the investigation of death. Evaluating the relationship between entomological data gathered from the scene can produce a reliable PMI estimate, in addition to knowledge of the decomposition patterns in the region, and regional climatological and environmental statistics since the individual's date of disappearance. Studies have been conducted by researchers in order to determine the developmental and successional patterns of insects and the gross morphological changes that occur in the body after death. This research has been carried out on both human and nonhuman subjects in various parts of the world. The environment plays a large role in the microscopic and macroscopic processes of decomposition and affects the insect species that colonize dead bodies. It is only with regional studies (to compensate for the variety of climates and insect regimens around the world) that a clear picture can begin to develop regarding decomposition rates and facilitate more accurate estimates of PMI. The following chapter will discuss the methods used in this study based on the previous research discussed in this chapter.

CHAPTER THREE

METHODS

Expected Results

I hypothesize that the shaded and exposed subjects placed in different environments or situations will experience different rates of decomposition based on several issues discussed in the previous chapter. First and foremost, ambient temperature should profoundly affect insect activity, the primary mode of biomass loss. The amount of sunlight the subjects are exposed to, and the direct relationship between exposure to sunlight and moisture, also should impact decomposition rates between the two study areas.

I also expect the two carcasses in this study to follow the same basic decomposition patterns as those in Shean et al.'s (1993) study. That is, I expect the exposed pig to reach its maximum bloat and to decompose sooner than the shaded pig. Again, this will be mainly due to the impact of temperature on insect activity.

The results from this study will aid local authorities in their estimations of postmortem intervals of discovered human corpses. Currently authorities must rely on knowledge of PMI approximations of past experience or on data gathered from such institutions as the Anthropology Research Facility (ARF) in east Tennessee, better known as Dr. William Bass's "Body Farm." While data from this facility is paramount to forensic anthropology, it is not always readily applicable to other geographic regions (Steadman 2003, Rhine and Dawson 1998), like Greenville, North Carolina. Therefore, I predict that local authorities can better adjust a corpse's PMI based on "Body Farm" data to a local and more relevant level.

Location

The current case study was conducted on the West Research Campus (WRC) of East Carolina University in Greenville, North Carolina. This extension of the main campus is approximately 8.5 miles west of the university and has a diverse array of plant and animal life. The vegetation at this facility is made up of tall grasses and small shrubs as well as different types of trees. Several animal species inhabit the area, such as rabbits and white-tail deer. The site also contains an assortment of birds including scavengers like crows and turkey vultures. The average maximum temperatures for Greenville, North Carolina for the months of August to January range from 87 to 52 degrees F. The minimum temperatures for the same months range from 69 to 31 degrees F (National Weather Service 2005). Normal precipitation for these months ranges from 0.5 to 1.51 inches per month (National Weather Service 2005).

I chose two sites, approximately 150 feet apart, on the WRC for the placement of the test subjects. One site was chosen as the "shaded" site and is inhabited by such tree species as sweet gum (*Liquidambar styraciflua*), wild cherry (*Prunus serotina*), winged sumac (*Rhus copallinum*), and dog fennel (*Eupatorium capillifolium*). The second site, chosen to represent an "open" area is dominated by high grasses and small shrubs including switch grass (*Panicum* sp.), summersweet (*Clethra alnifolia*), and swamp Tupelo (*Nyssa biflora*) (Knowles 2006).

Materials

Two domestic pigs (*Sus scrofa*) of 105 pounds and 160 pounds (shaded and exposed, respectively) were obtained for this study. I obtained the pigs under a state permit from Lakeview Packing Company in nearby Snow Hill, North Carolina. Both

specimens were humanely killed by Lakeview employees at 10:30 am on August 5, 2005 and deposited at their respective sites on the WRC two hours later. At the time of death, both pigs were suffering from the influenza virus and were deemed unfit for human consumption.

I constructed two chicken wire and polyvinyl chloride (PVC) pipe cages to protect the subjects from large scavengers. Each rectangular cage consisted of a PVC pipe frame measuring 4’ long, 2’8” wide, and 2’4” high and chicken wire of 1.0 inch mesh on all six sides. Each cage featured one removable side that allowed easy access to the subject carcasses for photographing, measuring, and insect collection. While the chicken wire mesh kept large scavengers such as raccoons and dogs at bay, the gauge of the mesh still permitted insects to have unhindered access to the carcasses and allowed the carcasses to be in direct contact with the ground.

Before positioning the pig carcasses into their respective cages, a plastic measuring tape was placed in the bottom of each cage. These measuring tapes remained in the cages for the duration of the study and were used to determine the amount of bloating experienced by each of the subjects. Data on rainfall amounts, humidity, and temperature were collected daily. Rain gauges were present at each site as well as digital thermometers that recorded the high and low daily temperatures. These digital thermometers also reported the maximum and minimum humidity levels.

During each site visit, I weighed the carcasses by lifting each cage up off the ground using a tripod/winch/scale apparatus (Figure 1). A tripod was positioned over each cage and consisted of three 2x4 inch planks of wood measuring 10 feet in length. The planks were secured at the apex of the tripod by a metal bracket and three large bolts.

A pulley was suspended from a hook hung from the bracket. A 1000-pound capacity winch was bolted to one of planks at shoulder height. A static nylon rope ran from the winch and up to the pulley. At the end of the rope hung a 220-pound capacity hanging Taylor brand scale with hook. Static nylon ropes tied at the top corners of the cages were joined, where they met at the center of the cage lid. Here the ropes were connected to the hook suspended from the scale. Using the winch, each cage could be lifted off of the ground and weighed with minimal effort. After I recorded the weights, the cages were put back in their initial position with little disturbance to the decomposition process. This exact apparatus is often used on farms for weighing small livestock animals such as sheep and goats.

Figure 1. Tripod apparatus used in weighing shaded and exposed subjects

Insect collection tools included forceps, glass collection jars, ethyl alcohol, a 10X magnifying glass. Insect identification relied on two insect reference sources (Castner, Byrd, and Butler 2001; Goff and Catts 1990).

Methods

On the morning of August 1, 2005, I chose two sites on the WRC for placement of the subjects. One site was chosen under a sweetgum tree, the second site was in the middle of a wide grassy area. Once the location of the sites was determined, I cleared the tall grasses and small shrubs from each site for placement of the cages. On the morning of August 5, 2005, a colleague and I wrapped the two subjects in plastic and drove the from the Lakeview Packing Plant in Snow Hill, North Carolina to the WRC in Greenville, North Carolina in a covered pick-up truck. The 30 mile drive took approximately 45 minutes.

Before positioning the pig carcasses into their respective cages, a flexible plastic measuring tape was placed into the bottom of each cage. I placed the shaded subject on its side within the cage with its fatal head wound down. This pig was then left beneath a sweetgum tree surrounded by other smaller trees and shrubs previously mentioned. These trees provided patchy shade from approximately 6 am to 11 am and total shade for the rest of the day. I then placed the exposed subject (head wound down) on its side within a cage. This carcass was placed in an open area of trees, which left it exposed to direct sunlight each day. A distance of approximately 150 feet separated the two sites in order to avoid competition between the two carcasses for visiting insects.

From August 5 to September 2, I visited the carcasses daily. Visitation lasted from 30 minutes to 90 minutes depending on the insect activity and ease of collection. The sites were visited less frequently as decomposition rates slowed. I visited the sites every third day from September 2 to November 6 with observations lasting from 20 minutes to 45 minutes. For the remainder of November 6 until January 8, I visited the

carcasses once per week with each data collection period lasting 20 minutes on average. All observations were made between 7 am and 7 pm.

Several pieces of data were collected for each subject during these visits. Climatic information gathered included the high and low temperatures and amounts of rainfall at each site, the weather conditions, and the high and low humidity levels. I noted the general condition of the site and the carcasses as well as the weights and girths of each subject. Measuring tapes placed beneath each subject remained in the cages for the duration of the study and were used to determine the amount of bloating experienced by each of the subjects. Girth measurements were taken at the greatest circumference of each pig, directly posterior to the ribcage. Insect presence, identification, and location were noted during each visit as well. I took digital photographs to visually document changes in the carcasses and to enhance the data collected.

I collected insects from August 5 to August 8, 2005. After the first 4 days no new species of insect visited the subjects and thus multiple specimens of the same species were not collected although insects continued to visit the carcasses for months. Collecting as few insects as possible further avoided any unnecessary disruption of the decomposition process or insect life cycle or feeding habits. I captured specimens using forceps, mainly from masses at the anus, mouth, feet, and eyes. Later, areas of the skin began to break open, and I captured some insects at these locations (abdomen and under the front legs/ front leg “armpits”).

Specimens were placed in glass collection jars. Each glass jar contained a preservation solution of 80% ethyl alcohol, as suggested by Castner and colleagues (1990) and Haskell (1990). I removed insects later from their respective labeled jars and

examined under a 10X magnifying glass. Insect species were identified using forensic insect identification cards (Castner et al. 1990) and Goff and Catts' entomology chapter (1990).

The above methods will effectively measure the environmental variables that this study seeks to gauge. Documentation and analysis of the measurements obtained will allow successful characterization of decomposition stages and subsequent determination of decay rates.

CHAPTER FOUR

RESULTS

In this chapter I will first discuss the climatic variables measured during the study (temperature, rainfall, humidity). The conditions experienced at each site are explained next. Third, the insects that visited the carcasses are examined as well as a description of each stage of decomposition. Addressed last are the results of the biomass loss and bloat measurements.

Temperature

According to the National Weather Service (2005), normal temperatures for this study area usually range from 87 to 52 degrees F (highs) and 69 to 31 degrees F (lows) for the months of August to January. As shown in Figure 2, actual high temperatures taken during this study ranged from 105.6 to 65.9 degrees F. The low temperatures range of 75.4 to 26.6 degrees F from August to January. As expected, daily temperatures at the exposed site were generally higher than those measured from the shaded site, by 1 to 15 degrees F. Night time temperatures usually differed by 0 to 6 degrees F between the two sites.

Humidity

Normal humidity levels for this area usually range from 75 to 96% (highs) and 25 to 52 % (lows) for the months of August to January according to the National Weather Service (2005). Actual high humidity levels recorded ranged from 73 to 94%, as shown in Figure 3. Low humidity levels ranged from 19 to 59%. Daily humidity levels were highest during the day and sank to the lowest levels during the night as expected. With

the two test sites within such close proximity to one another (150 feet), the humidity readings taken from the shaded site were used as representative of both sites.

Figure 2. Daily high and low temperatures for the shaded and exposed sites

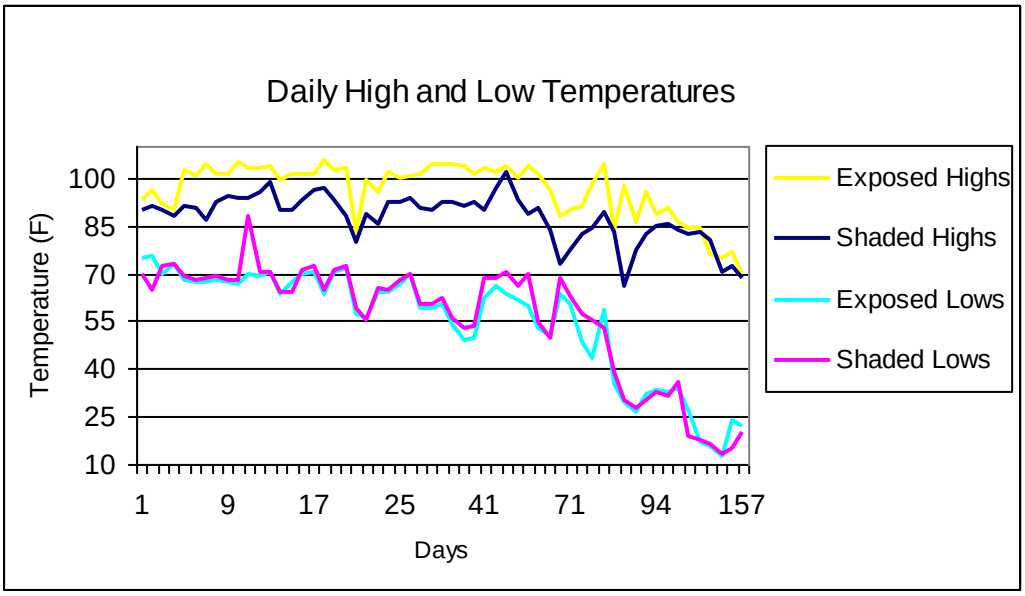
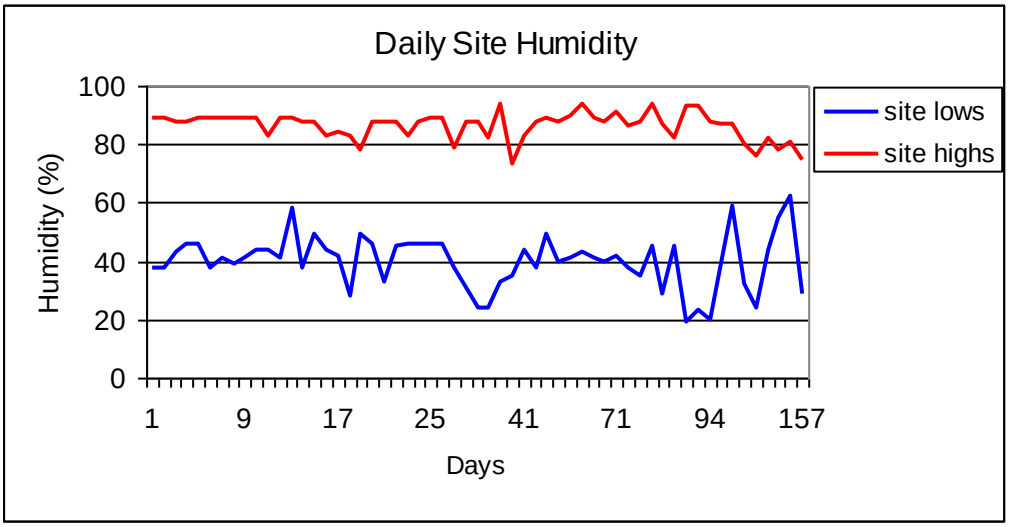


Figure 3. High and low humidity levels for the West Research Campus

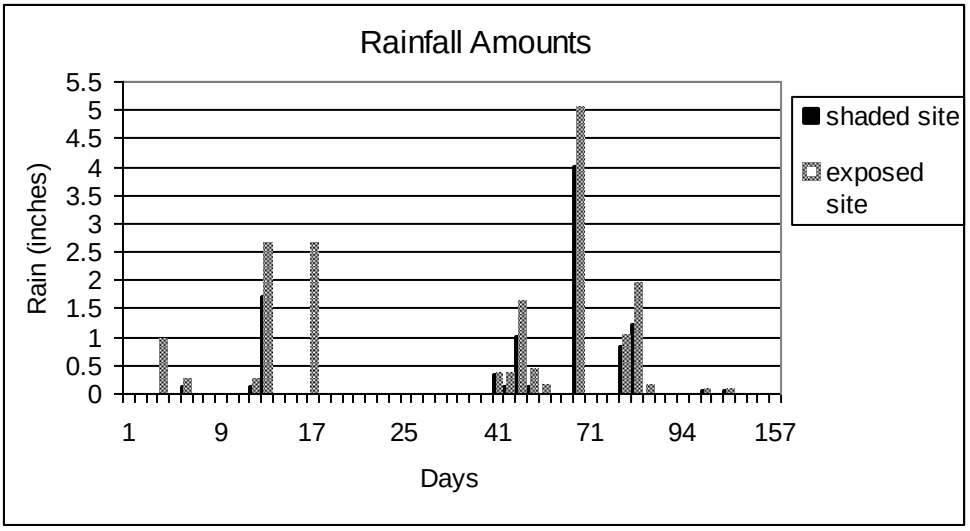


Rainfall

Greenville, North Carolina reportedly receives an average of approximately 25.0 inches of rain during the months of August to January (National Weather Service 2005). The study sites experienced unequal amounts of rainfall due to their location, as shown in

Figure 4. The shaded site, shielded by trees, sustained a total of 9.64 inches of rain from August to January. The exposed site, on the other hand, received nearly twice as much rain, with a total of 17.4 inches. Generally, if the exposed site received enough rain to collect in the gauge, the shaded site did as well. The rain during these periods was usually hard, but not necessarily long in duration. On occasion the exposed site collected rain in the gauge but the shaded locale did not. These were periods of light rain which tended to have a longer duration.

Figure 4. Amounts of rain experienced at each site



Site Conditions

Both the shaded site and the open site remained intact for the majority of the study duration. In early September (day 35), the trees sheltering the shaded pig began to lose their leaves. The leaves dried, shriveled, and some became small enough to fall through the top of the mesh cage and onto the carcass. Most leaves remained on top of the cage as they were too large to fall through the mesh. Dried leaves landed either on top of the cage or onto the carcass below and most were blown away by the wind, even those inside the cage. The loss of leaves from the trees caused the shaded subject to become

increasingly exposed to more sunlight as September and October progressed. In late November (day 108), all of the leaves of the surrounding trees had fallen and the carcass was completely exposed to the elements.

In only a few instances were the sites disturbed. Turkey vultures visiting the exposed site on days 3 and 4 defleshed the face of the exposed subject. They also were observed on day 28 but did no damage to the carcass. Upon arrival on day 7, it was apparent that the cages at both sites had suffered tampering. Two lengths of rope used to attach the shaded pig's cage to its scale were removed as were the fasteners of the exposed pig's cage door. Neither carcass looked to be disturbed in any way. On day 91 there was evidence of animal burrowing at two corners of the shaded pig's cage. The carcass itself was not disturbed. On day 150 the side of the shaded pig's cage was dented in, as though it had been knocked or pushed and this presumably caused the cranium to roll from its original resting place inside the cage.

Insects

All the insects sampled and identified during the study are common to the eastern portion of the United States and are expected visitors to carrion in eastern North Carolina. Arthropod variation did not vary greatly between the two study sites, however a few species frequented only the shaded carcass or the exposed carcass, but not both. The majority of insects arrived at each carcass within the first two weeks (Tables 1 and 2). Due to this study's lack of an entomological focus, each pig's insects are discussed according to their arrival day, location on the carcass, and activities. Life cycle stages of the various species were not noted.

Shaded Subject

Insects were present on the shaded subject within hours of death on day 1. Screwworm flies (*Cochliomyia macellaria*) were already laying eggs on the carcass. According to Castner et al. (2001), adult screwworm flies are often found on carrion in sunny and shaded environments, especially in the southeastern United States. A large number of Fire ants (genus *Solenopsis*) were present at the snout and mouth areas. These predacious ants are found in North Carolina and other areas and feed on the eggs of flies (Castner et al. 2001). The ants were seen carrying off the fly eggs at several times during the study.

By day 2 a large fly eggmass was present at the anus and ants were feeding on the eggs in the area. Flies were present at the mouth, as were a few common Carrion beetles (*Necrodes surinamensis*). The maggots had hatched from the eggs laid in the anus by day 3. The Hairy Rove beetle (*Creophilus maxillosus*) also arrived at the shaded carcass this day.

Table 1. Insect species visiting Shaded subject

Day Arrived	Common Name	Scientific Name	Location on Carcass	Day Last Seen on Carcass
1	Screwworm Fly Fire Ant	*Cochliomyia macellaria* genus *Solenopsis*	Torso Snout	59 59
2	Carrion Beetle	*Necrodes surinamensis*	Eyes, mouth, ears, hooves	13
3	Hairy Rove Beetle	*Creophilus maxillosus*	Under the head	6
6	Am. Carrion Beetle Clown Beetle Sexton Beetle	*Necrophila americana* genus *Hister* *Nicrophorus orbicollis*	Head, feet Grass in cage Torso, legs	13 56 6
17	Black Soldier Fly	*Hermetia illucens*	Torso	17

On day 4 carrion beetles were present at the eyes, mouth, ear, and hooves; adult flies were ovipositing behind the ears, and the maggot mass was still active and feeding

on tissues at the anus. Large dragonflies (2) were seen perched on the outside of the wire mesh of the shaded cage on day 5. At this time the carcass was infested with Carrion beetles. The beetles were feasting at the feet, abdomen, anus, under each front leg, and in the ears (Figure 5).

Figure 5. Insect infestation of Shaded subject five days after death

The most diverse array of insects was present on day 6. Dragonflies (4) were present at the cage exterior; Carrion beetles were still present (in fewer numbers) at the feet, face, and abdomen; screwworm flies visited the carcass as well. Three new species also arrived this day: the American Carrion beetle (*Necrophila americana*) on the face and feet, the Clown beetle (genus *Hister*) in the grass within the cage, and the Sexton beetle (*Nicrophorus orbicollis*) on the torso and legs. The American Carrion beetle, associated with carcasses in early and advanced decomposition, is found throughout the eastern United States and feeds on maggots. The Clown beetle also feeding on fly eggs and maggots, is usually found under the decaying corpse. The Sexton beetle is found at carcasses during early and advanced decomposition throughout the United States (Castner et al. 2001).

All previously mentioned insect species were present in some degree for the duration of the study. On day 17 a single specimen of the Black Soldier fly (*Hermetia illucens*) appeared that was not seen previously. This arthropod was seen only during this visit to the carcass. No new species arrived at the shaded subject for the rest of the study.

An overall pattern was seen in the behavior of the insects. Many ants and flies were present early in decomposition. As eggs were laid and maggots hatched, the various species of beetles quickly infested the carcass. This is likely because the beetles are predacious and eat the eggs and larvae of other insects. With an increase in beetles came a decrease in ants. Ants also eat fly eggs and were likely unable to compete with the larger carrion beetles for this food resource and thus left the carcass. There were several cycles in which many beetle larvae would be present on or under the carcass, followed by a period in which few larvae were present. During this time the larvae were migrating away from the carcass in order to begin their pupation stage. Essentially no insects were present on or after day 85 of the study. This is due to the lack of soft tissue remaining on the skeleton. With no tissues remaining, insects will be unable to use the carcass as an egg-laying site or as a food source.

Exposed Subject

As with the shaded subject, carrion insects were present on the exposed subject within hours of death (Table 2). Adult Screwworm flies (*Cochliomyia macellaria*) laid eggs in the mouth and anus upon arrival at the carcass on day 1. Clown beetles (genus *Hister*) were present in the mouth and a single butterfly (of the Lepidoptera order) was seen at the corpse's anus.

On day 2, the screwworm flies were concentrated around the pig's head. A large fly egg mass was deposited in the anus. The common Bumble bee (genus *Bumbus*) arrived at the carcass today and joined butterflies (2) at the anus. Carrion beetles (*Necrodes surinamensis*) were active beneath the head of the carcass. On day 3 the Sexton beetles (*Nicrophorus orbicollis*) arrived and a June Bug (*Cotinis nitida*) was collected from the puddle of purge fluids located at the mouth.

Table 2. Insect species visiting Exposed subject

Day Arrived	Common Name	Scientific Name	Location on Carcass	Day Last Seen on Carcass
1	Screwworm Fly Clown Beetle Butterfly	*Cochliomyia macellaria* genus *Hister* Lepidoptera order	Mouth Mouth Anus	94 85
2	Carrion Beetle Bumble Bee	*Necrodes surinamensis* genus *Bumbus*	Mouth Anus	6
3	June Bug Sexton Beetle	*Cotinis nitida* *Nicrophorus orbicollis*	Torso Torso	94 7
4	Am. Carrion Beetle	*Necrophila americana*	Anus	7
24	Black Soldier Fly	*Hermetia illucens*	Torso	24

Day 4 saw the arrival of the American Carrion beetle (*Necrophila americana*) to the exposed carcass. At this time these beetles were concentrated around the anus while the common Carrion beetles and Sexton beetles were busy burrowing holes into the skin, as seen below in Figure 6. The flies and various beetle species remain at the carcass for the duration of the study. No new arthropod species arrive until day 24. This was the first and last time the Black Soldier fly (*Hermetia illucens*) was seen at the exposed site. In addition, only one specimen of the Black Soldier fly was observed. No new species arrived at the shaded subject for the rest of the study.

Figure 6. Insects burrowing holes into Exposed subject's skin four days after death

A few species frequented one carcass but not the other. The Fire ant was very common at the carcass of the shaded subject, as was the Hairy Rove beetle. However, neither of these arthropod species were seen on the exposed subject. Dragonflies were seen on the exterior of the shaded pig's cage, but never on the carcass itself. Butterflies, Bumble bees, and June Bugs frequented the exposed carcass, but were never spotted near the shaded one. Of the species that frequented both carcasses, a greater number visited the shaded site. This is because the soft tissues of the shaded subject did not undergo dehydration and were able to sustain insect communities for a longer period of time as compared to the exposed subject.

All identified insects, except the bees, butterflies, Junes bugs, and Black Soldier fly, were seen at various points during the study carrying out the expected life stage cycles (adults laying eggs, eggs hatching into larvae, larvae migrating to find a pupation site, adults emerging from the pupa). Arthropods were also seen performing their anticipated roles (feeding on decaying tissues, laying eggs, preying on the eggs and larvae of other insect species, etc.). After a period rain, adult insects were slow to return

to the carcass and many of the developing larvae would be found dead in puddles of water within the cage or upon the carcass itself.

Some general observations were made in regard to insect activity. A large number of flies were attracted to the exposed carcass, but it is unknown as to why no ants were observed. The predacious beetles arrived to this carcass more gradually and in fewer numbers than to the shaded subject; beetle infestation was not seen in this carcass. It is possible that the warmer temperatures reached at the exposed site facilitate maggot development, but perhaps are not as hospitable to adult carrion insects. The adult beetles decreased after day 10, except for a few stray individuals that visited sporadically. Flies were observed almost every day of the study period, however no maggots were observed after day 12. This is likely the result of the carcass not being adequate for fly oviposition due to the condition of the skin. The skin of the exposed subject had dried and mummified due to dehydration early in the study. It would be difficult for maggots to burrow through such skin to reach any moist soft tissue remaining below. Essentially no insects were present on or after day 101 of the study. As explained above, flies were not laying eggs upon the carcass and without maggots, the predacious carrion beetles would have little reason to visit the exposed site.

Decomposition

Based on the pigs' gross morphological changes, I determined that the test subjects underwent four stages of decomposition (Table 3). The external changes listed in the right column are not meant to signify a sequence of events; it is simply a list of observations made during the stages of decay. Five stages are listed in Table 3 to show the next logical step in the sequence although the study ended before this stage was

reached by either subject. Table 4 lists the duration of each of the decompositional stages in days since death.

Table 3. Decomposition Stages and Morphological Changes

Stage of Decomposition	External Changes
Fresh/ Discoloration	Algor mortis Livor mortis Rigor mortis Skin Slippage Discoloration of head, thorax, and/or neck Marbling
Bloating	Early bloating of the abdomen Progressive bloating throughout entire body Maximum distention of abdomen reached
Active Decomposition	Release of gases Bloating resolved Decomposition of soft tissues Collapse of abdominal cavity
Skeletonization	Soft tissue continues to deteriorate Exposure of skeletal elements Partial skeletonization
Skeletal Decomposition	No soft tissue remains Skeleton disarticulated Bleaching, cracking, exfoliation of bone

Table 4. The duration (in number of days since death) of each stage

Number of Days Since Death	Shaded subject	Exposed subject
Fresh	1 - 3	1 – 2
Bloating	4 - 14	3 – 12
Decay	15 - 100	13 – 122
Skeletonization	101 – 157 +	123 - 157 +

Shaded Subject: Fresh/ Discoloration

The shaded subject remained in the fresh/ discoloration stage for 3 days. On the day of death the pig was undergoing livor mortis and the skin was intact and felt tacky to the touch. Marbling was evident on the animal's chest between the two front legs. There was a slight odor of decay. Two days after death the subject experienced early bloating, caused by the activity of internal microorganisms or putrefaction.

Shaded Subject: Bloating

For this subject, the bloating stage lasted from 4 - 14 days after death. It was difficult to determine when the fresh/ discoloration stage ended and the bloating stage began due to the overlap between the two stages. The shaded subject was fully bloated by the third day after death with legs extended from the swelling, as pictured in Figure 7.

Figure 7. Shaded subject at maximum bloat three days after death

Figure 8. Shaded subject bloated and discolored nine days after death

Insect activity penetrated the skin and maggots were emerging from a hole on the medial aspect of the pig's right front leg. Marbling proceeded to a blackening of the chest, front legs, head and throat eight days after death. By the ninth day the rest of the pig's skin had turned yellow in color and began to dry out. The shaded subject remained in the bloating stage until 12 days after death.

Shaded subject: Active Decomposition and Skeletonization

During the bloating period, gases and fluids were exiting the carcass and as a result, the body was deflating. This marked the initiation of the active decomposition period. The active decomposition stage (lasting over 3 months) and the skeletonization stage (lasting nearly 2 months) overlap to such an extent that they essentially occurred simultaneously. In short, as more and more soft tissue decomposed (active decomposition), further skeletal elements became exposed (skeletonization).

Soft tissue decomposed after the bloat stage ended 12 days after death and the abdominal cavity collapsed as a result of the liquefaction/ decay of the internal organs. The exposure of skeletal elements of the distal portion of both front legs as well as that of the right rear leg began on the thirteenth day. The ribcage first began to skeletonize 15 days after death, while the left rear leg began a day later.

Figure 9. Collapse of Shaded subject abdominal cavity 13 days after death

Soft tissue decay and the skeletonization stage continued 35 days after death. On this day the pelvis and ribcage became disarticulated from the surrounding bones. The ribcage thus collapsed as a result of the disintegration of the cartilage. Bones in the shoulder and spine began to emerge on the forty-fourth day since death. The skull followed on day 50 and was completely skeletonized by day 68.

Decomposition continued until day 101. From this day until day 157 (the last day of the study) skin and hair continued to decompose and desiccate. Pieces of dried skin and hair still remained adhering to the bones until the end of the study. One long piece of mummified soft tissue extended along the spine and smaller pieces clung to the ribs and remained on the bottom of the cage. This strip of tissue could possibly be the remnants of a longitudinal ligament or even a thoracolumbar fascia, a wide sheet of dense connective issue spanning the length of the spine.

Figure 10. Shaded subject skeletonized 150 days after death

Exposed Subject: Fresh, Discoloration and Bloating

Initial stages of decomposition proceeded rapidly for the exposed pig. This subject only remained within the fresh/discoloration stage for two days after death. Much overlap existed between the fresh/discoloration and the bloating stages (lasting 7 days). Lividity was noted and decomposition was evident via pink foam which was present at the nostrils on the day of death. Several morphological changes were evident two days following death, such as marbling on the right side of the chest and abdomen and blackening of the left side of the chest, abdomen, and the entire head. Yellowish fluid bubbled from the mouth on day 2; on this day the pig had already reached its maximum bloat size (Figure 11) as a result of the putrefaction process. The skin was intact besides the fatal head wound. The decay odor of this carcass on day 2 was more intense than that of the shaded one.

Figure 11. Exposed subject at maximum bloat two days after death

By five days after death the skin had dried significantly and several spots on the head and legs looked almost like leather. By seven days following death the skin covering the entire body had turned black, except for a small spot at the left shoulder and rump (Figure 12). This form of discoloration was the result of exposure to sunlight and dehydration, not the same mechanism by which marbling occurs. Three days after death insect activity had broken through the skin. This began the release of gas from the carcass. Bloating subsequently subsided from day 3 to day 8.

Figure 12. Discoloration of Exposed subject seven days after death

Exposed Subject: Active Decomposition and Skeletonization

As soft tissue decomposed (active decomposition) skeletal elements became exposed (skeletonization).The active decomposition stage (lasting over 4 months) and the skeletonization stage (lasting over 1 month) overlap to such an extent that they essentially occurred simultaneously. Thus, the two stages are discussed here together.

Skin and soft tissue was also removed from the snout of the exposed pig by turkey vultures the third morning since death. The cranium underwent more attack by turkey vultures since that day and was defleshed up to the ears and under the chin. Part of the mandible had been broken off and was found approximately 8 feet away from the outside of the cage in the tall grass. Judging by the size of the mandibular fragment, the vultures apparently were able to pull it through the mesh of the cage wall and discarded it after removing the remaining flesh.

Liquid bubbled from two gaping holes that were present at each shoulder and the skin became broken in several more places such as the medial right front leg, left front "armpit," mid-lower abdomen, and the center of the chest by four days after death. The odor of decay increased as methane gas escaped from the carcass and as temperatures rose.

Nine days after death the first rib was exposed. The skin had, at this point, several holes in it, but no other bones became exposed until the thirteenth day. On this day the distal bones of the right front and rear legs and the ribcage became more exposed. From 14 to 42 days since death, the skin on the exposed carcass became increasingly dry and the progress of skeletonization slowed. No further significant skeletonization occurred

until 44 days following death, when the jaw and neck areas became exposed as well as further exposure of the rib cage (Figure 13).

Sixty-eight days after death the ribcage became disarticulated as did the femur and tibia of the right rear leg. It was not until 76 days from death that the proximal portions of the two front legs started significant skeletonization. The dried skin decomposed a slight amount between 76 and 101 days since death, but no further exposure of skeletal material resulted until day 122 when the skull became completely skeletonized.

Figure 13. Revelation of Exposed subject's ribcage 44 days after death

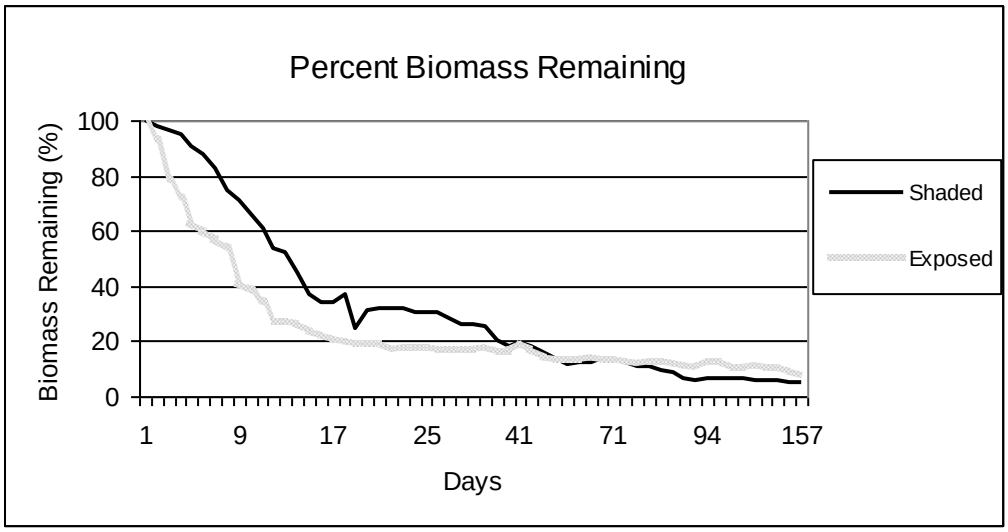
Biomass Loss

The two test subjects underwent different rates of decomposition over the course of the study. The rate of decomposition was figured as daily percent (%) of original body weight remaining since a 55 pound difference in initial weight existed between the two carcasses. The shaded pig decayed at a slower rate at first than the exposed pig (Figure 14). In fact in the first week following death the exposed subject lost 43% of its original biomass while the shaded subject lost only 17.5%. By the end of the second week, the

exposed carcass had decreased to 26.6% of its initial weight and the shaded carcass still retained almost half of its body weight.

Decomposition of both carcasses then slowed until the end of the study period. During the first two weeks the shaded and exposed subjects were losing approximately 3.9 and 4.4 % of their body weights per day, on average. Decay slowed in the following two weeks to daily losses of an average of 2.2% for the shaded subject and 0.91% for the exposed subject. Decomposition rates slowly and steadily decreased until the end of the study. One hundred and fifty-seven days after death, the shaded pig retained 4.9% of its original body weight and the exposed pig still maintained 8.2%.

Figure 14. Decomposition curves for Shaded and Exposed subjects

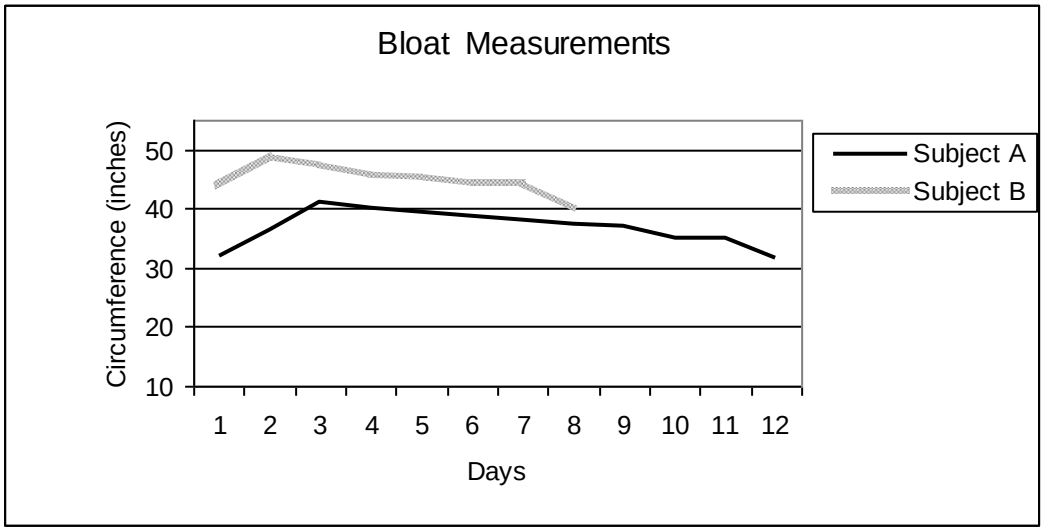


Bloat

The amount of bloating experienced by the two test subjects was distinct. The shaded pig originally measured 32.0 inches in circumference hours after death. At the time of maximum bloat on the third day since death, the subject measured 41.0 inches. After this day, bloat values slowly decreased. The final measure of bloat was taken 12 days following death: 31.5 inches. The exposed pig had an initial circumference of 44.0

inches and reached its maximum bloat 2 days after death with a measurement of 49.0 inches. As shown below in Figure 15, bloat measurements constantly decreased until 8 days after death at which time the subject's circumference was recorded at 40.0 inches. This was the final bloat measurement taken for the exposed subject. "Bloat" measurements for the subjects subsided on days 12 and 8, respectively.

Figure 15. Bloat measurements for Shaded and Exposed subjects



On these days it became obvious that, as time passed, these measurements became less of an evaluation of the animals' bloat and more a measurement of biomass loss. "Girth" measurements for the pigs continued until it was obvious that the abdominal cavity was empty and further measurements would only reflect the amount of dried skin remaining. Girth measurements ended 35 and 19 days after death, respectively.

Both subjects experienced a steady drop in bloat after reaching their maximum size. Both subjects experienced a notable drop in bloat 12 days after death. The shaded pig dropped in girth by 3.5 inches while the exposed pig decreased more dramatically with a loss if 9.5 inches. This relatively substantial and simultaneous loss of girth in both subjects may be indicative of the maturation of insect species at both sites. Eggs laid at

the same time on both subjects potentially could have reached a point in development in which maggot or larval digestion of tissue became more voracious.

CHAPTER FIVE

DISCUSSION

The purpose of this case study was to investigate decomposition rates in eastern North Carolina and to determine which environmental factor(s) most influenced this process. Subjects placed in different environments were expected to decay at different rates. The shaded and exposed subjects additionally were expected to follow the same basic decomposition patterns as those seen in Shean et al.'s (1993) study since all the decomposition subjects were undergoing the same treatment (i.e., placement in either a shaded or exposed site within a wooded temperate environment). These two predictions will be evaluated on the basis of the results presented in the previous chapter.

First, ambient temperatures were surmised to profoundly influence the primary mode of biomass loss, insect activity. The amount of sunlight exposure and the direct relationship between exposure to sunlight and moisture also should impact decay rates. These factors in turn would result in different decomposition rates between the two subjects. This prediction regarding temperature and sunlight was correct. When the carcasses were fresh and temperatures were high, the carcass exposed to the sunlight, was frequented by a greater number of insects than the shaded one. This resulted from the greater temperatures reached at the exposed site, which increased insect activity and encouraged maggot growth egg development. This positive association between high temperatures and increased insect activity facilitated the rapid biomass loss by the exposed pig during the early weeks of the investigation.

Second, it was presumed that the two carcasses would follow the same pattern of decay as in Shean et al.'s (1993) study with the exposed pig reaching maximum bloat and

decomposing sooner than the shaded pig. This assumption similarly was based on the impact of temperature on the decomposition process. The relative rate that the exposed subject attained of maximum bloat was correct. The exposed subject achieved a maximum bloat of 49.0 inches by day 2 while the shaded one reached its maximum bloat of 41.0 inches on day 3. The exposed site's higher temperatures facilitated greater methane gas production by putrefactive bacteria in the pig's gut.

The presumption that the exposed pig would decompose sooner than the shaded pig on the other hand was incorrect. The exposed pig first lost a higher percentage of biomass per day than the shaded pig (43% versus 17.5 %). This was primarily due to the warmer temperatures experienced at the exposed site. Flies and other insects are most active during warm temperatures since they facilitate maggot growth. Proliferation of microorganisms associated with putrefaction also greatly increases with higher temperatures. The prolonged exposure to high temperatures and direct sunlight however caused the soft tissues of the exposed subject to dehydrate and become unsuitable for insect use, both as a site for oviposition and as a food source for developing maggots and larvae. Decomposition thus slowed and fewer and fewer insects frequented the exposed carcass as time progressed. The shaded subject's soft tissues meanwhile still could support insect communities and decay steadily proceeded. This pig reached an advanced stage of skeletonization by the end of the study with only 4.9% of its original body weight remaining. Skin still adhered to the exposed carcass on the other hand, which maintained 8.2% of its original biomass by the end of the study.

This project furthermore confirmed many general observations made in previous decomposition investigations (Mann et al. 1990). These results include (1) temperature's

strong impact in the decomposition process, (2) insect activity as the primary mode of soft tissue destruction, and (3) the first flies will arrive at a dead body placed outside in "literally…a few seconds," especially during periods of warm temperatures (Mann et al. 1990: 109).

Mann et al. (1990) stated that rainfall, even if severe, did not seem to influence maggot or other larval activity. The results from this research do not support entirely this assertion. Maggots survived by staying within the carcass body cavity during periods of rain. Beetle larvae however were found dead in puddles of standing water on or around the carcass on days following heavy rains. The drowned beetle larvae were seen mostly at the exposed carcass since the shaded pig was protected from most of the precipitation by the overhanging trees. It is likely that the widespread death of beetle larvae at the exposed site influenced the decay rate of that carcass since those beetles were not able to mature into adults and lay eggs for future beetle communities.

Each stage in the decomposition process was found to be unique. The fresh/ discoloration stage (akin to the *fresh* stage in Table 3) is the shortest of all stages; decomposition begins immediately after death, so in warm temperatures it takes very little time for the morphological changes to become apparent. This stage lasted 2 to 3 days and was characterized by algor and livor mortis, skin slippage, and marbling. Many flies and/ or ants were present early in decomposition. As eggs were laid and maggots hatched, the various species of beetles quickly infested the carcass. This is because the beetles are predacious and eat the eggs and larvae of other insects. The bloating stage (*bloated*) lasted for 7 to 10 days and was made apparent by the swelling of the carcasses, especially in the abdominal area. This swelling was due to the production of methane gas

produced by the pigs' intestinal bacteria and accelerated by the warm late summer temperatures. Flies were present in all stages of the decomposition process while various species of carrion beetles were most prevalent during the late bloating period and early active decay period. The strong decay odors during these stages likely attracted many species of insects. The active decay stage (*decay*) was characterized by the release of the bloating gases, destruction of soft tissues, and subsequent collapse of the abdominal cavity. This stage lasted 3 to 4 months. Such a long duration was due to the cooler temperatures experienced during the fall/winter months which slowed insect activity and thus decomposition. The skeletonization stage (*postdecay*) spanned from 1 to over 2 months. This stage was still in progress for the exposed subject on the last day of the study period. During this stage, as more soft tissue deteriorates, more skeletal elements become revealed. More flesh was removed from the shaded subject before the start of this stage because the flesh remained supple longer; the flesh of this subject did not experience dehydration and mummification as the exposed subject did.

There were a couple of overall important observations that came from this case study. First, the most complicating aspect of the case study was the extent of overlap between all of the stages. The start of one stage did not necessarily signify the end of the previous stage. Second, all of the variables that influence the rate of decomposition are so interrelated that it is virtually impossible to control one without impacting the others. The lack of animal scavenging likely hindered the rate at which biomass was lost. Measures had to be taken, however, to prevent such scavenging as it would have resulted in the loss of most of the carcasses before decomposition rates were able to be observed. Regarding the rates of decomposition between the two sites, the treatment of shade versus exposure

had the largest impact during the active decay stage. The protection from the sun provided by the trees kept the soft tissues from dehydrating and mummifying; this allowed the insect communities continual use of the carcass as an egg-laying site and food source.

Comparisons

Test subjects studied in different parts of the world experienced different rates of decomposition (Table 5) compared with these specimens. The differences between rates of decay can tell investigators which environmental factors are most influential in their geographic areas. Avila and Goff's (1998) pig subjects progressed through the stages of decomposition in 23 to 35 days in Hawaii. This rate differed greatly from the results of my case study in eastern North Carolina. The carcasses in both studies remained in the fresh stage for a comparable amount of time probably because the climates in the two areas were similar during the time of year they were conducted. The subjects in Hawaii went through the rest of the decay stages at a faster rate that the North Carolina subjects which is likely due to several factors. First, Avila and Goff used smaller pigs than those in this study (33 to 60 pounds versus 103 to 158 pounds) which allowed them to pass through the stages more quickly since far less biomass had to decompose. Second, Avila and Goff noted the arrival of different insect species than what were present in North Carolina which suggests perhaps the carrion insects in Hawaii are more voracious eaters of flesh than those in North Carolina. The tropical and moist conditions of the environment where the pigs were placed in Hawaii likely inhibited the dehydration of soft tissues. The subjects in North Carolina experienced dehydration and mummification of soft tissues, which retarded decomposition in the decay stages.

Table 5. Durations of decomposition stages by authors and locations

Study (Authors & Location)	Duration of Fresh Stage	Duration of Bloated Stage	Duration of Decay Stage	Duration of Postdecay/Dry Stage
Avila & Goff (1998) Hawaiian Islands	1 to 2 days	1 to 3 days	5 to 9 days	16 to 21 days
Galloway et al. (1989) Arizona	1 to 2 days	4 days	14 days to 4 months	1 to 3 months
Rodriguez & Bass (1983) Tennessee	4 to 36 days	3 to 19 days	6 days to 4 months	13 to 27+ days
Leone (2006) North Carolina	2 to 3 days	7 to 10 days	3 to 4 months	1 to 2+ months

Galloway et al.'s (1989) retrospective study of human decomposition in Arizona showed the fresh stage of decomposition to last 1 to 2 days. This is comparable to the duration of the fresh stage in North Carolina, despite the differences in aridity between the two locations. This could result from the possibility that humidity and aridity do not strongly influence soft tissue destruction at such an early point in the decomposition process. Hotter temperatures and differential insect activity could account for the shorter duration of the bloat stage in Arizona as compared to North Carolina. Hotter temperatures would facilitate faster achievement of a maximum bloat and more intense insect activity could lead to puncture of the skin, release of gas, and subsequent resolution of the bloat stage sooner than in the North Carolina study. The duration of the decay and postdecay stages in both studies is comparable due to the dehydration and mummification experienced in both locations.

Rodriguez and Bass (1983) observed cadavers placed within the ARF at various times of the year and made the observations on decomposition rates as shown in Table 5. There is a wide range of days for the duration of the fresh stage in the Tennessee study; four days in the fresh stage would reflect a corpse placed for study in the warm part of the

year while a span of 36 days reflects placement during wintry months. Four days is comparable to the results of my case study and is likely due to the similarity of temperatures between Tennessee and North Carolina in August. The length of the bloat stage in the two locations is analogous. This probably results from the similarity in size between the human and the pig subjects, the similarity of temperatures, and the presence of some of the same insects at both locations (carrion beetles, clown beetles, and rove beetles). The decay stage in Tennessee can last from six days up to four months. The short span of six days likely reflects decomposition occurring under optimal conditions of near 30% humidity and temperatures around 70 degrees F (Clark et al. 1997) while four months can result from climatological conditions similar to those in North Carolina. Rodriguez and Bass reported a length of 13 to 27 days for the postdecay stage. This duration shorter than what was experienced in my study, but this is because the corpses in the Tennessee study were still under observation at the time of publication of Rodriguez and Bass's results.

Conclusions

The results of this case study sought to answer questions pertaining to the expectations set forth at the beginning. These expectations included (1) subjects placed in different environments (shaded versus exposed) would experience different rates of decomposition and (2) the subjects would follow the same basic decomposition patterns as those in Shean et al.'s (1993) study. Specifically, the exposed subject would reach maximum bloat and decompose sooner than the shaded subject. The above expectations were based on the impact of temperature and insect activity on the decomposition process.

Ambient temperatures most strongly affect the differential decay of human bodies. A corpse exposed to higher temperatures therefore will reach maximum bloat sooner than one exposed to cooler temperatures. High temperatures additionally can accelerate some decomposition processes, such as speed of bloat and maggot development. Hot weather also can retard a corpse's decay later in the decay process by dehydrating tissues and thus making the corpse inhospitable to insects as an egg-laying site and as a food source. The results of this study truly illustrate the importance of taking all environmental and climatological variables into consideration when estimating the PMI of a human corpse.

Future Research

There exist several possibilities for future research on decomposition rates in eastern North Carolina due to the number of interrelated variable involved in decomposition. Future investigators should address the impact of soil pH on the decomposition of bodies left on the soil surface. Observing decomposition rates during a different portion of the year (say, January to July) additionally could reveal an alternative decompositional relationship between the two sites or uncover the presence of new insect fauna. Test subjects also could be buried at various depths at an appropriate location and their decay rates compared with (1) each other and (2) with corpses of similar size at the ARF in east Tennessee. The east Tennessee versus eastern North Carolina comparison could provide further data on the impact that humidity levels and elevation have on soft tissue destruction. Another potential avenue to explore could include clothing the subjects and documenting the progression of decay as it relates to that variable. The area of decomposition study that needs far more investigation is that of entomology (i.e., why do

certain insect species show up at a corpse when they do, why do they leave when they do, why are some species more prevalent in one geographical area over another).

The results of this study are important for both forensic anthropology in eastern North Carolina and for the field of forensic anthropology in general. Conducting such a study in eastern North Carolina allows investigators in the region to have a better understanding of the process and rate of decomposition as it occurs locally. Instead of just knowing that temperature most influences the decay process investigators can see how variations in temperature between sites 150 feet apart can change the rate of soft tissue destruction. It is this rate of decomposition that will be used by officials to estimate a corpse's PMI. It is not enough to know that a body was placed outside to decompose, we must seek to understand all of the complexities that exist in the corpse's environment (i.e., was the body found beneath a tree, was the body wrapped and therefore untouched by insects, what was the weather like since the individual's date of disappearance). As for the field of anthropology in general, this study answers the call for experiments conducted on the local level. It is only with such local studies that the compilation of knowledge can begin and a wider pattern of decomposition rates can be seen.

In order to reach its full potential, this information on decomposition rates in eastern North Carolina must be made available to a wider audience. To do this, articles based on the information presented above will be composed and submitted to various forensic science journals. Such journals include the Journal of Forensic Science, the American Journal of Forensic Medicine and Pathology, and the Forensic Science Review. Also, a copy will be available in the East Carolina University library and a copy will be given to the Medical Examiner's Office at the Brody School of Medicine. Ideally, local

authorities would be able to access these journals, study the information within, and be aided in their determination of a time since death of corpses in their area.

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APPENDIX A: HIGH AND LOW TEMPERATURES FOR SHADED AND EXPOSED SITES

Days	Exposed Highs	Shaded Highs	Exposed Lows	Shaded Lows
1	93	90	75	70
2	95.9	91	75.4	65
3	92	90	70	72.1
4	90	88	73	73
5	102.7	91.1	67.9	68.9
6	100.3	90.5	67.5	67.9
7	104.2	86.6	67.3	68.4
8	101.3	92.3	67.9	69.3
9	100.9	94.1	67	67.9
10	104.8	93.4	66.8	67.9
11	103.2	93.8	70	87.8
12	103	95.4	69.3	70.4
13	104	98.8	70.6	70.4
14	99	89.6	63.4	64.3
15	101.5	90	67.5	64.3
16	101	93.1	70	71.3
17	101.4	96.3	70.6	72
18	105.6	96.7	63.4	64.8
19	102.5	93.1	70.2	70.7
20	102.8	87.7	71.8	72
21	82.8	79.9	57.2	58.9
22	99.4	88.4	56.2	55.4
23	95.8	85.3	64.1	65.5
24	102	92.3	64.3	64.8
25	100.2	92.5	66.6	67.9
26	100.3	93.4	69.7	69.5
27	101.2	90.4	59.2	60.1
28	104.6	90	59.2	60.1
29	104.4	92.3	60.5	61.9
32	104.4	92.2	54.2	56
35	103.9	91.1	48.8	52.9
38	101.3	92.3	49.5	53.3
41	103	89.8	62.1	68.2
44	102	96.8	65.7	68.2
47	103.9	101.9	63.7	70.6
50	100.2	92.9	61.7	66.2
53	103.9	88.6	59.9	69.5
56	101.3	90.4	52.7	54.9
59	96.1	83.3	50.2	49.5
68	88.2	73	63.5	68.2
71	90	77.3	60.5	63
74	91.3	82.1	48.2	56.9
76	97.9	84	43.6	55.1
79	104.6	89.5	58.5	52.9
82	83.4	83.2	35.4	38.9

Days	Exposed Highs	Shaded Highs	Exposed Lows	Shaded Lows
85	97.2	65.9	29.2	30.2
88	85.9	77.6	26.6	27.7
91	95.6	82.1	31.9	30.1
94	88.9	85	33.4	32.8
101	90.7	85.7	32.9	31.3
108	85.9	83.5	34	36
115	84	82.5	27.1	18.9
122	83.9	83.2	17.1	17.3
129	76.2	80.7	15.4	16.1
135	74.5	70.6	12.4	13.1
150	76.9	72	23.6	15.3
157	69.7	68.2	22.1	20

APPENDIX B: HIGH AND LOW HUMIDITIES AT THE WEST RESEARCH CAMPUS

Days	Site Lows	Site Highs
1	38	89
2	38	89
3	43	88
4	46	88
5	46	89
6	38	89
7	41	89
8	39	89
9	41	89
10	44	89
11	44	83
12	41	89
13	58	89
14	38	88
15	49	88
16	44	83
17	42	84
18	28	83
19	49	78
20	46	88
21	33	88
22	45	88
23	46	83
24	46	88
25	46	89
26	46	89
27	38	79
28	31	88
29	24	88
32	24	82
35	33	94
38	35	73
41	44	83
44	38	88
47	49	89
50	40	88
53	41	90
56	43	94
59	41	89
68	40	88
71	42	91
74	38	86
76	35	88
79	45	94
82	29	87

Days	Site Lows	Site Highs
85	45	82
88	19	93
91	23	93
94	20	88
101	38	87
108	59	87
115	32	80
122	24	76
129	44	82
135	55	78
150	62	81
157	29	75

APPENDIX C: RAINFALL AT SHADED AND EXPOSED SITES

Days	Shaded Site	Exposed Site
1	0	0
2	0	0
3	0	0
4	0	0.9
5	0	0
6	0.09	0.2
7	<0.1	<0.1
8	0	0
9	0	0
10	0	0
11	0	0
12	0.09	0.2
13	1.7	2.6
14	0	0
15	0	0
16	0	0
17	0	2.6
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
32	0	0
35	0	0
38	0	0
41	0.3	0.3
44	0.1	0.3
47	1	1.6
50	0.1	0.4
53	0.008	0.1
56	0	0
59	0	0
68	4	5
71	0	0
74	0	0
76	0	0
79	0.8	1
82	1.2	1.9
85	0	0.1

Days	Shaded Site	Exposed Site
88	0	0
91	0	0
94	0	0
101	0	0
108	0.04	0.05
115	0	0
122	0.04	0.05
129	0	0
135	0	0
150	0	0
157	0	0

APPENDIX D: BIOMASS LOSS FOR SHADED AND EXPOSED SUBJECTS

Days	Exposed Subject	Shaded Subject
1	158	103
2	146	101
3	124	99
4	113	98
5	100	93
6	98	90
7	90	85
8	85	77
9	65	73
10	61	68
11	54	63
12	44	55
13	44	54
14	42	46
15	38	38
16	35	35
17	33	35
18	32	38
19	31	25
20	31	32
21	31	33
22	27	33
23	29	33
24	29	31
25	29	31
26	27	31
27	27	29
28	27	27
29	27	27
32	29	26
35	26	21
38	26	19
41	31	20
44	27	19
47	23	15
50	22	14
53	22	12
56	22	13
59	23	13
68	22	14
71	22	14
74	20	13
76	19	11
79	21	11
82	20	10
85	19	9
88	18	7

Days	Exposed Subject	Shaded Subject
91	17	6
94	21	7
101	20	7
108	17	7
115	17	7
122	18	6
129	17	6
135	17	6
150	15	5
157	13	5