AVIAN SCAVENGING, MUMMIFICATION, AND VARIABLE MICRO-ENVIRONMENTS AS FACTORS AFFECTING THE DECOMPOSITION PROCESS IN WESTERN MONTANA

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AVIAN SCAVENGING, MUMMIFICATION, AND VARIABLE MICRO-ENVIRONMENTS
AS FACTORS AFFECTING THE DECOMPOSITION PROCESS IN WESTERN MONTANA

By

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Thesis

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Avian Scavenging, Mummification, and Variable Micro-environments as Factors Affecting the Decomposition Process in Western Montana

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The purpose of this research study was to empirically study the temporal order of events of postmortem changes in Missoula, Montana utilizing pig (Sus scrofa) cadavers as human proxies by documenting postmortem changes and rate of soft tissue decomposition of three pigs over the course of one year and 19 days. The data from this study will be compared and contrasted to studies that have occurred elsewhere. A full understanding of the postmortem changes and rate of soft tissue decomposition in this area will help forensic anthropologists better understand why the postmortem interval (PMI) may be different in western Montana than in other states or countries. The current research study reveals that previous methods for estimating the PMI using accumulated degree-days (ADD) and total body score (TBS) are not appropriate for Montana, as the climates are too disparate. Building a body of longitudinal data that documents environmentally related soft tissue decomposition or change will be a first step towards developing a decomposition sequence and time scheme that can be used to more accurately estimate the PMI in this region. In Montana a number of partially decomposed cases enter the medico-legal system each year. Thus, greater knowledge about the postmortem period will be a significant contribution to members of the medico-legal community as well as the criminal justice system. In addition, this data could be extended to similar climatic zones.

Key Words [Decomposition process, avian scavenging, mummification, total body score (TBS), accumulated degree-days (ADD), postmortem interval PMI]
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Chapter 1: INTRODUCTION

Forensic anthropology can be defined as the application of principles and methods of physical anthropology to cases of medico-legal or forensic proceedings (Simmons and Haglund, 2005; Komar and Buikstra, 2008; Dirkmatt et al. 2008). One of the critical questions asked of forensic anthropologists by death investigators is how long an individual has been deceased. If a forensic anthropologist can closely approximate the postmortem interval (PMI), this or death investigators narrow down the list of suspects, determine whether the individual was the victim of a crime, identify the unknown individual, and even help to solve the case (Litherland et al., 2012). The PMI in Montana is difficult to establish, as most of the data sets and methods developed to estimate the PMI have been developed for only a few bioclimatic zones (Galloway, 1997; Megyesi et al., 2005; Vass, 2011). Bodies found deceased in Texas or Florida, for example, will decompose at a different rate than bodies in Montana. Applying the same PMI methods to all climatic zones will likely result in inaccurate estimates of PMI. Likewise, the condition or environment in which the body is discovered (e.g., water submersion, hanging, burial, burned) can also affect the PMI estimation (Wilson-Taylor, 2013).

The problem with trying to estimate a PMI in a bioclimatic zone that is disparate from the bioclimatic zone where the methods were established is that the data collected at the disparate site will not correspond with the pre-established data sets. Decomposition rates and stages have been researched in bioclimatic zones (Payne 1965; Rodriguez and Bass, 1983; Galloway et al., 1989; Mann et al., 1990; Vass et al., 1992; Wilson-Taylor, 2013) that are vastly different than those in Montana (Terneny, 1997; Barnes, 2000; Wagster, 2007; Gonder, 2008; Dudzik, 2009; Parsons, 2009; McKeown et al., 2011). In order to establish a PMI for cases in Montana, new
data sets and different methods need to be developed specifically for bioclimatic zones in Montana.

Is it necessary to expose the problems with the current PMI estimates to prevent forensic anthropologists from providing death investigators with inaccurate probabilistic evidence, which could compromise or hamper an investigation. The current methods for estimating PMI from Megyesi et al. (2005) and Vass (2011) are problematic due to the subjectivity involved in arriving at the conclusions. Both methods require the researcher to exercise their “best judgment” to score 1) a percentage of decomposition from one percent to one hundred percent (Vass, 2011) and 2) degree of decomposition exhibited on individual segments of the body (Megyesi et al., 2005). Those numbers are employed in equations to estimate the PMI. In the current research study, the observed data were used in the equations but most of the equations failed to provide accurate estimates of the PMI, with the exception of the PMI estimates based on entomology—even with large standards of error being considered.

Judges have often expressed apprehension in their judicial opinions about heavily subjective evidence, especially in the area of scientific evidence, fearing that such evidence will improperly elevate the status of the evidence in the minds of the jury. “The fear is that evidence which is in essence mostly the subjective opinion of one person will effectively be camouflaged by the trappings of scientific objectivity and be accorded more weight by the jury than it deserves” (Greenberg and Kunich, 2002, p. 250). The inaccurate evidence could exonerate a guilty person or incriminate an innocent person. Results from the current study as well as Dudzik (2009) and Suckling (2011) reveal the flaws with the Megyesi et al. (2005) method of establishing an accurate PMI estimate, particularly when applied in western Montana. Results
from the current study also reveal the flaws with the Vass (2011) PMI equation when applied to decomposition in Montana.

One of the most glaring differences in the decomposition process in Montana compared to the decomposition studies in other parts of the country is that Montana experiences hot, dry summers and cool to cold temperatures with low humidity during the other seasons of the year (Terneny, 1997; Wagster, 2007; Dudzik, 2009; Parsons, 2009). The consequence of the temperature and humidity on the cadavers in the current study is that within the first 7 to 10 days of summer decomposition, each cadaver desiccated to the point of mummification. Many of the previous studies from other parts of the country do not document such a rapid onset of mummification (Rodriguez and Bass, 1983; Bass, 1997; Megyesi et al. 2005). Adipocere was not observed on the cadavers in the current research. It is thought that adipocere development is a result of moisture in more humid climates (Wilson-Taylor, 2013), and it does not seem to develop in the arid climate of Montana; although this statement cannot be currently substantiated due to inadequate data.

The greatest observation from this research is that there are too many variables to consider in each bioclimatic zone to attempt to make a broad statement about how decomposition progresses from stage to stage, and what you can expect to find during each stage of the process to generalize across large geographic areas like North America (Galloway et al., 1989; Megyesi et al., 2005; Wilson-Taylor, 2013). We need to identify general decomposition patterns for each bioclimatic zone in order to systematically estimate PMI.

The research goal was to determine what variables had the biggest effect on the decomposition specimens, in Montana. This thesis demonstrates that decomposition in Montana
is substantially different throughout the state, and different than decomposition in other areas of the county.

In order to examine the decomposition processes in western Montana, 3 pig (*Sus scrofa*) cadavers were placed in a research facility on a ranch just outside of the Missoula city limits. Data from the decomposition process, climatic variables, entomological activity and vertebrate scavenging were observed for over one year. Researchers involved in determining stages of decomposition for estimating PMI need to be cognizant of the taphonomic impacts vertebral scavengers can have on the decomposition process (Bass, 1997; Reeves, 2009; McKeown et al., 2011; Suckling, 2011; Pharr, 2012; Spradley et al., 2012). Likewise, the taphonomic process of mummification will have a significant effect on the decomposition process, primarily by slowing the decomposition process.
Chapter 2: LITERATURE REVIEW

Forensic anthropology can be defined as the application of principles and methods of physical anthropology to cases of medico-legal or forensic context. In the United States, forensic anthropologists are also trained in forensic archaeology and often act as recovery team leaders to recover and analyze remains (Simmons and Hagleund, 2005; Komar and Buikstra, 2008; Dirkmatt et al., 2008). Forensic anthropology also utilizes the methods and principles of forensic archaeology to search for, recover and excavate not only human remains but also any buried evidence in a forensic, medico-legal and/or humanitarian setting (Litherland et al., 2012). Most forensic anthropologists need to be educated in and equipped with a particular skill set for assisting medico-legal or death investigators. Some of the techniques forensic anthropologists and archaeologists utilize include survey and mapping techniques, landscape analysis, search methods, excavating skills, evidence collection, sampling soils and entomological evidence, identifying human and non-human bones, and knowledge of how to properly preserve remains in order to transport them safely to a laboratory or medical examiner’s office for analysis. For the purpose of assisting in the identification of unrecognizable human remains, the forensic anthropologist applies scientific methods to the remains. There are many reasons why it is difficult to identify remains including advanced decomposition, animal scavenging, fire or explosions, purposeful modification by a perpetrator, and other reasons. Even with the modifications, it is often possible for forensic anthropologists to estimate a postmortem interval (PMI), sex, ancestry, stature, any trauma inflicted upon the individual perimortem, and postmortem damage. This information could be used to identify the individual. Along with helping to identify the individual and what killed the individual, one of the biggest questions
asked of a forensic anthropologist is how long the individual has been deceased. The time since
death (TSD) or PMI can help death investigators narrow down the list of suspects, if the
individual was the victim of a homicide or simply give them a time of death when the death was
not witnessed. The PMI can be difficult to estimate as most of the data sets and methods utilized
to estimate the PMI have been developed in only a few climatic zones.

This thesis was designed to investigate the pattern and rate of soft tissue decomposition and
postmortem changes on three pig (*Sus scrofa*) cadavers deposited on the ground surface in two
different micro-environments—full sun versus full shade—just 7.62m away from each other, in
the macro-environment of western Montana from August 2011 to August 2012. Payne et al.
(1968) and later Schoenly et al. (2007) have demonstrated the effectiveness of pigs as proxies for
humans. This literature review will discuss many of the variables affecting decomposition
including: variations in micro- and macro-environments, climate, weather, temperature, soil, and
deposition sites (surface versus burial), forensically relevant entomology and post-mortem
interval (PMI) or time-since-death (TSD) estimation, and cadaver scavenging. Since there is no
recognition of a standard guide for measuring rates, stages, and processes of decomposition,
previous studies from Montana as well as several other states and countries will be reviewed in
order to show the contradiction between the current methods utilized to study decomposition;
some of those methods come from Galloway et al. (1989), Megyesi et al. (2005), and Vass
(2011). This literature review will show that decomposition is a complicated process that does
not fit neatly into categories that can be measured. Instead, each decomposition process needs to
be approached as a singular event, with the independent variables contributing, collectively, to
the outcome.
Decomposition Process

For many years, researchers have attempted to categorize the process of decomposition into various stages for the purpose of estimating the postmortem interval (PMI) or time-since-death (TSD) to assist medico-legal professionals; however, much of the data used is based on qualitative data such as color and discoloration, bone exposure, decomposition purge, odor, bloat, hair loss, mummification, scavenging, skin slippage, arthropod activity, and marbling to name a few (Clark et al., 1997). Utilizing quantitative data only, such as the point scoring system used in Megyesi et al. (2005), is problematic because the process of decomposition rarely fits into measurable, predictable stages; rather, many different variables affect decomposition. The PMI of a cadaver cannot be estimated by simply summing up the quantitative data, you must also utilize the qualitative data (Galloway, 1997; Megyesi et al., 2005). The data relevant to decomposition studies include, but are not limited to: size of cadaver, time of exposure, cadaver deposition (e.g. above ground, below ground, in water, indoors, outdoors), temperature, humidity, elevation, latitude, associated materials (clothed versus unclothed), odor, color changes, texture, environment, ecology, wind speed, precipitation, vegetation, micro- and macro-habitat, soil type and drainage capabilities, entomological activity, scavenging, missing or scattered skeletal elements, medications, and trauma (Mann et al., 1990; Shean et al., 1993; Clark et al., 1997; Wilson-Taylor, 2013).

Stages of Decomposition

It is agreed upon by multiple-disciplines that there are several stages of decomposition. First, there is a fresh stage where there is no entomology present and the only discoloration that is present comes from the pooling of blood (lividity, hypostasis), caused by an accumulation of
blood in the small vessels of the dependent areas secondary to gravity (DiMaio and DiMaio, 2001; Klepinger, 2006). The length of the fresh stage is dependent upon several variables. The temperature will either speed up or slow down the decomposition process at the deposition site. According to DiMaio and DiMaio (2001) a dead body can lose heat through radiation, conduction, and convention. Hence, that loss of body heat is passive. If the temperature of the environment surrounding a body is higher than the body’s normal temperature of 37°C (98.6°F), the body will get warmer. If the temperature of the environment surrounding a body is the same as the body, the body will stay the same. If the temperature is lower than 37°C (98.6°F), the body will cool. Further, several additional factors will affect temperature, including where the body is placed (e.g. on concrete—which is an excellent heat conductor, a bed—which acts as a heat insulator, on hot or cold ground, in a freezer or morgue), how large the body is (smaller bodies will cool faster than larger bodies), whether the body was placed in full sun or full shade, and whether or not the body is clothed. Finally, other important variables that can retard the process of decomposition and prolong the fresh stage, include burial type and depth, cold water submersion, bodies wrapped tightly in plastic or fabric, as well as other variables (Rodriquez and Bass, 1985; Galloway, 1997; Wilson-Taylor, 2013). If nothing is present to impede or slow the process of decomposition, it will resume. Decomposition is accelerated by obesity, heavy clothing, and sepsis, all of which keep the body warm (DiMaio and DiMaio, 2001, p. 33). Following the cessation of the heart, internal aerobic microorganisms deplete the tissues of oxygen, which results in the destruction of cells (Gill-King, 1997; Carter et al., 2007). This is the beginning of the decomposition process referred to as autolysis. During the process of autolysis, livor mortis, algor mortis, and rigor mortis ensue (Marks et al., 2009). According to Vass et al. (2002), autolysis can begin within minutes of death, and is largely affected by moisture and
temperature. According to Rodriquez (1997), microorganisms and bacteria inside the body (e.g. *Clostridium, Bacteroides*) initially break down the cells and internal tissues very quickly, but their by-products (e.g. ammonia, alcohol, methane, hydrogen sulphide, carbon dioxide, nitrogen) increase the pH inside the body, the bacteria are depleted of oxygen and the decomposition process slows. According to DiMaio and DiMaio (2001), autolysis occurs through an aseptic chemical process caused by intracellular enzymes, and it is accelerated by heat, slowed by cold, and stopped by freezing or the inactivation of the enzymes by heat. The breakdown of cells and the build-up of organic acids and gases result in the onset of putrefaction (Klepinger, 2006), which depends on two main factors: the body and its environment.

Putrefaction is analogous to the stage of decomposition referred to as bloat or early decomposition. During putrefaction, the fermentation and bacteria in the intestinal tract spread throughout the body resulting in bloating, discoloration, marbling, “skin slippage,” bullae formation, and odor change (Clark et al., 1997; DiMaio and DiMaio, 2001; Klepinger, 2006; Marks et al., 2009; Wilson-Taylor, 2013). Bloat can occur in all locations of the body, but is the most noticeable in the abdomen and face (Wilson-Taylor, 2013). Due to the increase in odor and decomposition purge fluid, arthropods are drawn to the decomposing body. In addition, the chemical reactions that induce putrefaction can cause the body to swell to the point where the integrity of the skin is compromised to the point of rupturing. In the case of a rupture, the ruptured skin would allow oxygen back into the cadaver which can precipitate the next stage of decomposition, referred to as active decomposition or decay (Micozzi, 1986; Clark et al., 1997; Gill-King, 1997; Carter and Tibbett, 2008). The early stage is followed by the decay or active decomposition stage.
During the decay or active decomposition stage, the soft tissues rapidly break down (decomposes) and much of the cadaver’s biomass is reduced, primarily due to the fact that a cadaver is comprised of 60-80% water (Carter and Tibbett, 2008). Simultaneously, additional decomposition fluids or volatile fatty acids (VFAs) seep into the ground beneath and around the cadaver creating what is referred to as the cadaver decomposition island (CDI) (Carter and Tibbett, 2008). The VFAs cause vegetation and soil pH changes, which are significant indicators of this particular stage of decomposition (Vass et al., 1992). The VFAs can stain the ground dark brown to black around the cadaver, and will generally kill the vegetation for 100 days up to a year after deposition (Wilson-Taylor, 2013). Although the process of autolysis and putrefaction break down tissues, the majority of decomposition is due to the actions of noncadaveric organisms, especially insects and scavengers. During this active decomposition stage, larval activity from Diptera and Coleoptera reach their height. Scavenging, if allowed, could be a significant mechanism for soft tissue loss, as large amounts of the cadaver can be consumed by rodent and/or carnivorous scavengers (Galloway, 1997; Haglund, 1997a; Klippel and Synstelien, 2007). Both decomposition factors (insects and scavengers) will be discussed in greater detail below. The decay stage continues until the fly larvae migrate away from the body in order to pupate, and there is a marked presence of beetles migrating to the cadaver to feed. This phenomenon represents the onset of the advanced decay or dry stage (Gennard, 2007; Carter et al., 2007; Wilson-Taylor, 2013).

The advanced decay or dry stage generally represents a decrease in the speed of decomposition and a slowing of cadaver mass loss (Carter and Tibbett, 2008). According to Wilson-Taylor (2013) and Galloway et al. (1989), during the advanced decomposition stage, deflation of the body will be observed. Galloway et al. (1989) reveals that an increase in maggot
activity in the thoracic and abdominal cavities can occur due to the draining of body fluids. This is generally followed by dehydration of the outer surface of the cadaver, which causes the skin to turn leathery and eventually harden. Even though the surface is hard to the touch, the undersurface may still be moist and odoriferous. The surface tissue can then change from soft and pliable to a hard mummified shell. Additionally, there can be skeletonization of areas that have little soft tissue (e.g. cranium, facial elements, finger and toe phalanges). Galloway et al. (1989) notes that adipocere development can also be observed during this stage and is usually found in areas with high humidity. Dry or arid conditions can desiccate all or part of the body before the agents of decay and entomological gorging have disposed of the soft tissue, resulting in partial or complete mummification (Klepinger, 2006). The optimal conditions for mummification are high environmental temperature, high altitude, low humidity, and adequate ventilation (Quigley, 1998; Klepinger, 2006). Extremely dry environments usually promote mummification; whereas, extremely wet environments usually promote adipocere development (Clark et al., 1997, pgs. 157-8). Because cadavers comprise 60-80% water, their breakdown has been described as a “competition” between desiccation and decomposition and external factors such as temperature and humidity mainly “determine the outcome of the contest” (Micozzi and Sledzik, 1992, p. 759).

The last stage of decomposition for this study is referred to as the skeletonization stage. Skeletonization is described as the removal of soft tissue from bone. Remains can be considered to be completely skeletonized if all soft tissue is removed, or partially skeletonized if only portions of the bone are exposed (Clark et al., 1997, pgs. 159-60.) Skeletonization is possible in hot, humid climates where insects can consume remains in days or weeks (Bass, 1997). Lower temperatures will slow decomposition, but skeletonization can still occur (Komar, 1998). Several
studies are also interested in how skeletonization can occur due to both avian and terrestrial scavenging (Bass, 1997; Haglund, 1997a; Reeves, 2009; McKeown et al, 2011; Suckling, 2011). Very few decomposition studies seem to know how to account for scattered, disarticulation, or bone loss due to scavenging when trying to estimate a PMI.

Of the many stages of decomposition utilized by various researchers, very few studies conclusively assert how long a cadaver will remain in each stage of decomposition. Gill-King (1997) discusses how cadavers can spend more time in 1 stage than another. He refers to this as “dwell time” (p. 104). Many of the researchers provide general time ranges for each stage, but warn that many variables affect the decomposition process and those variables need to be accounted for when trying to estimate a TSD or PMI. In arid environments, mummification can occur naturally-leading to soft tissue preservation for hundreds of thousands of years (Quigley, 1998).

One of the first researchers to describe the process of decomposition according to stages was a French army veterinarian and entomologist by the name of Jean Pierre Mégnin. Mégnin (1894) delineated the decomposition of the human body into 8 distinct stages. In a subsequent study, Reed (1958) expanded upon the research by Mégnin and others but found it more “convenient to divide dog carcass seres into 4 stages” (p. 220) (fresh, bloated, decay, dry). In addition to the seres stages, he also adopted a 5-term scale of quantifying the abundance of insects on the carcasses. Whenever possible, Reed would record the actual number of insects. When an accurate count was precluded due to the high number of insects, he used his 5-term scale to record abundance (e.g. rare, scarce, medium numbers, common, abundant). One of the problems with Reed’s study was his inability to account for the scavenging that had taken place with his
dog cadavers. He noted the scavenging, but had no way of allowing it into his evaluation because scavenging is not considered to be one of the stages of decomposition.

According to Wilson-Taylor (2013) researchers commonly employ 4-5 decomposition stages as described above, but additional stages have also been utilized (Payne 1965; Rodriguez and Bass, 1983; Galloway et al., 1989; Bass, 1997; Clark et al., 1997; Marks et al., 2000; Megyesi et al., 2005; Klepinger, 2006; Sharanowski et al., 2008). Some of those stages are discoloration (Reed, 1958), dry remains (Tibbett and Carter, 2008) moderate (Komar, 1998), pre-deposition (Fitzgerald and Oxenham, 2009), and extreme decomposition (Galloway, 1989). An additional decomposition stage of dry has been developed involving the entomological and biochemical modifications to the human body (Sharanowski et al, 2008).

In Galloway et al. (1989) 5 categories and stages of decomposition are also utilized, but those stages are defined as fresh, early decomposition, advanced decomposition, skeletonization, and extreme decomposition respectively. However, within these stages of decomposition there are secondary categories which do not imply a sequence of events, but simply represent the overall condition of the remains (Galloway et al., 1989, p. 608). More importantly for this study, Galloway et al. (1989) have established criteria and characteristics for decomposition in hot, arid climates. Arid climates can cause soft tissue to desiccate which can lead to mummification. Galloway et al. (1989) conducted a retrospective study of 189 cases from southern Arizona and found that bloating and rapid desiccation occurred early in the decomposition process-causing mummification. The mummification caused a decrease in the entomological activity as the dried tissue is not an ideal environment for oviposit or larval feeding. Consequently, a hard, mummified shell could reside at the death scene for hundreds of years unless the remains are displaced by terrestrial or avian scavenging. Galloway et al. (1989) provides guidelines for
estimating TSD based on the arid Southwest decay process. The arid conditions appear to alter the decomposition stages from previous studies. Exposure outdoors, with high temperatures and low humidity, speeds up the early decomposition stage which results in mummification within 2 weeks. Scavenging by insects and carnivores can reduce the remains to the skeletal stage in 4 to 6 months, and bleaching of the bone in approximately 9 months. Remains discovered in closed structures demonstrate prolongation of the early decomposition stages but rapid progression to skeletonization in as little as 3-4 months following a moist decomposition process (Galloway et al., 1989, p. 615). No statistical data for PMI calculations were presented. Galloway et al. (1989, 1997) provides a broad estimation of time in each stage of decomposition in dry climates. The fresh stage can last from 1-7 days, the early decomposition stage can last from 1-8 days, the advanced decomposition stage can last from 4 days to 9 months, the skeletonization stage can last from 2 months to 1 year, and the extreme decomposition stage can last from 6 months to 18 months.

**Variable Micro-environments with Surface Deposition**

Several decomposition studies (Shean et al., 1993; Bass, 1997; De Souza and Linhares, 1997; Sharanowski et al., 2008; Fitzgerald and Oxenham, 2009) have been conducted utilizing shaded and sunlit habitats. Shean et al. (1993) notes that bloat size, occurrence of blow fly larvae, body weight, and ambient temperatures were compared. Maggot activity appeared to be the biggest factor in the overall rate of decomposition between the 2 micro-environments, due to the 2 separate temperatures in those micro-environments. However, although Sharanowski et al. (2008) set out to research decomposition patterns as well as insect succession, they were primarily concerned with the comparative analysis of the seasonal profusion and rate of succession of members of the orders of Diptera (blow flies) and Coleoptera (beetles) as well as
other forensically relevant entomological activity. They were not particularly concerned with the competition between decay and desiccation; avian and terrestrial scavenging resulting in disarticulation, dispersal, or loss of skeletal elements; temperature, climate, and weather; or soil presentations. Results from Sharanowski et al. (2008) indicated that habitat was only a factor in the decompositional rate of carrion in the spring season.

Several studies have focused on examining decomposition following burial below ground (Payne et al., 1968; Rodriguez and Bass, 1985; Vass et al., 1992; Quigley, 1998; Carter and Tibbett, 2008; Spitz, 2006; Forbes and Dadour, 2010; Pastula and Merritt 2012). This study will focus on examining decomposition following deposition on the ground surface. The following studies have, likewise, focused on above ground decomposition (McKinnerney, 1978; Galloway et al., 1989; Haglund et al., 1989; Mann et al., 1990; Shean et al., 1993; Clark et al. 1997; Galloway, 1997; Haglund, 1997a; Haglund, 1997b; Love and Marks, 2003; Selva et al., 2005; Spitz, 2006; Sharanowski et al., 2008; Fitzgerald and Oxenham, 2009; Reeves, 2009; Suckling, 2011; Alfieri et al. 2012; Pharr, 2012) It is widely accepted that burial of a cadaver underground will decrease the rate of decomposition. According to Rodriguez (1997), it has been inferred that cadaver decomposition following burials proceeds at a speed of 8 times slower than cadaver decomposition following surface deposition. According to Spitz (2006), in the pathology literature-a rule of thumb and Casper’s Law in Stub and Frederick (1989) agree that the degree of decomposition for 1 week of deposition on the surface equals 2 weeks of deposition in water, and 8 weeks deposition in a burial.

Megyesi et al. (2005) proposed one of the first methods to combine gross observations of the body based on total body scores to calculate accumulated degree days as a method to estimate PMI. According to the Megyesi et al. (2005), PMI can be estimated by scoring decomposition
using a quantitative point-based system while taking into account the temperatures where the remains were discovered. The research developed a scoring system for decomposition on different regions of the body (head and neck, trunk, limbs). In order to produce a total body score (TBS), the different regions of the body were scored and then summed. The TBS is independent of the environment of deposition because the researchers opted to focus only on the condition of the body. Megyesi et al. (2005) also retrospectively measured the association of amount of decomposition with the accumulated degree days (ADD) to estimate TSD or PMI. A total of 68 human cases were examined and scored. The decomposition scores were transformed through a regression equation to predict ADD. According to Megyesi et al. (2005), ADD accounts for approximately 80% of the variation of decomposition that takes into consideration accumulated temperature, not just time. In other words, Megyesi et al. (2005) believe that temperature is the core decomposition factor and all of the other variables are peripheral. They stress the importance of averaging the high and low temperature at the site, and adding it to the next day in order to accumulate degree days. Megyesi et al. (2005) uses a sequential scoring system so that the final decomposition scores reflect the total accumulated decomposition that has taken place.

In order to account for the differential decomposition that occurs in different body segments, the remains were scored independently in 3 specific areas of the body: (1) the head and neck, including the cervical vertebrae; (2) the trunk, including the thorax, pectoral girdle, abdomen, and pelvis; and (3) the limbs, including the hands and feet (Megyesi et al 2005, p 2).

After the TBS has been achieved, and the ADDs have been calculated-the following formula is applied to try to establish the PMI:

\[
\text{Log}_{10}\text{ADD} = 0.002(\text{TBS} \times \text{TBS}) + 1.81 \pm 388.16
\]

In order establish the PMI, the \text{Log}_{10}\text{ADD} score is located on the ADD chart in order to establish the date in which the ADD number was achieved. For instance, in this study, if a
Log_{10}ADD equals 890, the date closest to 890 would be used. On 9/14/2011 of this study, an ADD score of 892.35 was achieved. This would mean that the PMI estimate would be on or around 9/14/2011 +/- the standard error of 388.16 with a confidence interval of 80%.

Of interest to the current study, Megyesi et al. (2005) removed 2 cases from their case study because they were outliers. One of those cases was from Missoula, Montana. This method is problematic as it was developed without consideration of mummification or scavenging events, and the bodies were analyzed and scored based only on pictures from the actual forensic cases.

Vass (2011) has developed 2 formulas to estimate PMI for human decomposition; 1 formula is for above ground (aerobic) decomposition and the other formula is for human ‘burial’ (anaerobic) decomposition. The formula that will be utilized in the current study is the formula for aerobic PMI estimation. The formula for Vass (2011) is as follows:

\[
\text{PMI (Aerobic)} = \frac{1285 \times (\text{decomposition/100})}{0.0103 \times \text{temperature} \times \text{humidity}}
\]

Where

\(1285\) = a constant, representing the empirically determined ADD value at which volatile fatty acid (VFA) liberation from soft tissue ceases.

\(\text{Decomposition}\) = the single value, or range, between 1 and 100, representing the best estimation of the extent of total body soft tissue decomposition.

\(0.0103\) = constant, representing an empirically determined measure of the effect of moisture on decompositional rates.

\(\text{Temperature}\) = the value in degrees Celsius (°C) of either the average temperature at the site on the day the corpse was discovered or the average temperature over a period of time.

\(\text{Humidity}\) = a value between 1% and 100%, representing either the average humidity at the site on the day the corpse was discovered or the average humidity over a period of time (Vass 2011, p. 35).
Vass (2011) reveals that his formulas for PMI are intended to provide law enforcement personnel with an easily attainable, fast, and fairly accurate estimate of PMI to begin their investigation before receiving a more complete laboratory analysis. Vass (2011) reveals that the rate of decomposition and temperature are connected by Van’t Hoff’s Law, which states that the speed of chemical reactions increases two or more times with each 10°C rise in temperature.

Both methods for estimating the PMI from ADD (Megyesi et al., 2005; Vass, 2011) have been found to work well in areas of the United States where soil type, temperature, humidity, soil moisture, and vegetation are similar to those studied at the University of Tennessee-Knoxville’s Forensic Anthropology Center. The problem with utilizing these ADD methods to determine PMI is that climatic conditions vary greatly from state to state, from country to country, and between seasons of the year.

Wilson-Taylor (2013) emphasizes that the methods for estimating PMI are not equally reliable, and some may be outdated and need to be replaced with better methods. She also notes that there has been little advancement in statistical applications pertaining to PMI estimates from the gross morphological changes of the body, which is the method most commonly utilized by anthropologists. The ADD approach is problematic as it assumes regularity to the decomposition process, which is not realistic. There are just too many variables at play during decomposition. Finally, Wilson-Taylor (2013) suggests statistically linking observations of the appearance of the body with environmental variables to improve accuracy and reliability of PMI estimates.

Previous decomposition studies in Montana, utilizing ADD to test estimation of PMI, have been conducted by Parsons (2009) and Dudzik (2009) at a site within the Lubrecht Experimental Forest. In her abstract, Dudzik (2009) refers to her study as a “sister study” to that of Parsons

Parsons (2009) conducted a systematic study of pig decomposition to study the postmortem interval in west central Montana. Parsons (2009) showed how the rate of decomposition of 2 pigs in a high, arid altitude, with cold temperatures is affected by the climate and insect activity in August and October. She found that the climate in west central Montana produces slower rates of decomposition than those observed in Tennessee and other parts of the United States. Parsons (2009) found that the August cadaver spent 1 day in the fresh stage of decomposition, 6 days in the early stage of decomposition, 244 days in the advanced stage of decomposition, and 0 days in the skeletonization stage of decomposition. She found that the October cadaver spent 180 days in the fresh stage of decomposition, 1 day in the early decomposition stage, 0 days in the advanced decomposition stage, and 0 days in the skeletonization stage. Parsons (2009) also found that the use of ADD to determine TSD or PMI estimates was accurate and consistent with previous PMI studies despite the differences in weather patterns and climate. Parsons (2009) hypothesized that the use of ADD to predict the TSD will incorrectly calculate dates of death when applied to areas with prolonged periods of stasis due to long, cold winters with heavy snowfall. She found that the ADD model was accurate, and had to reject her null hypothesis. However, she cautions that the accuracy of the ADD model from Megyesi et al. (2005) does not take into account the state of mummification for the August cadaver and the result is that the TBS will not change enough to produce ADD estimations that differ from current estimations; however, the degree days will
continue to accumulate. Parsons (2009) also cautions using the ADD method of predicting PMI from Megyesi et al. (2005) because of the large standard of error (+/- 388.16 days), and the fact that in cold temperatures the PMI predictions could be accepted even though those estimations could be off by weeks or months. Parsons (2009) also found a higher abundance of arthropods collected in comparison to a study conducted by Barnes (2000), who conducted an observational entomological analysis of 2 pig cadavers in the Lubrecht Experimental Forest.

Dudzik (2009) researched the freeze-thaw cycle as it affects the postmortem interval and also assessed the rates and patterns of decomposition in west central Montana. Dudzik (2009) hypothesized that pig cadavers experiencing a prolonged period of stasis due to cold temperatures over the winter months would show a slower decomposition rate that would differ from other decomposition studies conducted by Payne (1965) and Bass (1997). She also hypothesized that the ADD method from Megyesi et al. (2005) would produce a much lower PMI than the actual date of death due to the frozen stasis and arid climate at the research site at Lubrecht Experimental Forest in west central Montana. Dudzik (2009) found that both research cadavers remained in the fresh stage over the winter, and showed similar patterns of decomposition during the thaw, in the spring. The pattern of decomposition differed from the August cadaver in the Parsons (2009) study, as the August cadaver advanced rapidly through the decomposition stages resulting in mummification within a short period of time and incomplete decay. Insect activity also differed in the 2 studies. In both studies, mummification of the remains due to lack of humidity was also apparent after the spring thaw.

to estimate PMI using TBS and ADD. The highest TBS was a 24, from SS-2 on 7/15/2009, on SS-3 on 6/06/2009, on SS-3 on 7/15/2009, and from SS-2 on 7/06/2009. The lowest TBS reached was a 6, from SS-3 on 12/07/2008. Dudzik (2009) also concluded that the ADD method of estimating PMI from Megyesi et al. (2005) showed that the rapid advancement to the late decomposition stages due to warm temperatures and lack of humidity adversely affected the accuracy of the method (p. 94). The carcasses remained in the fresh stage throughout the winter and showed similar patterns of decomposition during spring thaw.

The insect activity on the summer pig from Parsons (2009) differed from the late fall and winter specimens. Finally, Dudzik (2009) opined that although Megyesi et al. (2005) concluded that temperature was the most important variable in the process of decomposition, relative humidity is also an important factor. The lack of humidity in the arid climate of Montana slows the decomposition process, and often results in mummification. In order to accurately score ADD using TBS, mummification and scavenging also need to be considered in the PMI estimate. Dudzik (2009) suggested that changes need to be made to the Megyesi et al. (2005) method to allow for the wide array of geographic climate conditions that a cadaver can encounter. Two additional studies by Wagster (2007) and Gonder (2008) also researched decomposition patterns at the Lubrecht Experimental Forest. Instead of pig cadavers, both researchers utilized wolves in their studies. Gonder (2008) also observed bear, deer, and mountain lion carcasses. Gonder (2008) researched PMI estimates for wildlife to assist law enforcement officers to track poachers and their behavior in the mountain west. Gonder (2008) observed slower rates of decay than in other areas of the country where temperature and humidity are higher, but found consistency of decomposition rates and insect succession among carcasses placed at Lubrecht Experimental Forest throughout the duration of her study. Wagster (2007), like Dudzik (2009), researched the
freeze-thaw process and the insect succession patterns during the duration of her study. Wagster (2007) concentrated on entomological activity, but found that the rates of decay and the processes that surround them are extremely unpredictable.

A decomposition study by Terneny (1997) was conducted in Missoula, Montana. Two pig cadavers were utilized in the study. One specimen was buried on 04/05/1996, and the other was placed on the ground surface on the same day and remained at the site until April of 1997. Insects were collected, identified, and recorded. Terneny (1997) found that the decay rates for the 2 specimens occurred more slowly than studies in other parts of the country, likely due to the colder climate in Montana. She found that the buried specimen decomposed at a slower rate than the surface specimen. The buried specimen was exhumed twice during the study to record the decomposition characteristics. She found that the buried specimen remained at the fresh stage for 2 days, the bloated stage for 7 days, the active stage for 66 days, the advanced stage for 26 days, and the skeletonization stage for 262 days. The surface specimen bloated and deflated twice, likely due to the increase and decrease of ambient temperatures. Terneny (1997) observed more entomological activity on warmer days than cooler days. Finally, Terneny (1997) found that most all stages of decomposition were lengthened but the sequence of decomposition for the specimens was similar to the previous studies that have been done in the United States, which supported her hypothesis that the same principles of the decay process apply even in states that have different environments and climates from those in northwestern Montana.

In the semi-arid climate of western Montana, temperature is one of the most important factors in decomposition; however, due to the overall low humidity rates throughout the state cadavers can experience mummification, resulting in a prolonged stage of advanced decomposition compared to other areas in the United States and other countries. The mummification can last for
years, which would mean that the cadaver may never advance to the skeletonization stage of decomposition. Strub and Frederick (1989) reveal that moisture escapes from the surface membranes and through the skin resulting in mummification. Temperature and humidity are the key factors in the desiccation of the body. Ideal conditions for mummification include hot temperatures, low humidity, and proper ventilation. Poor conditions for mummification include climates with high, prolonged humidity. In arid regions, partial mummification of skin may occur in 4 days (Quigley, 2006), with complete mummification in as little as 2 weeks. The speed with which mummification occurs varies with the weather. Furthermore, skeletonization of surface deposition generally does not occur without the aid of scavengers (McKeown et al., 2011). Obviously, cadaver mummification and skeletonization due to scavenging activity would make PMI estimates from ADD using the Megyesi et al. (2005) method, difficult if not impossible. In addition, these factors would also make the PMI estimates from Vass (2011) difficult to ascertain.

**Entomology**

A multitude of studies discuss how insect activity influence cadaver decomposition (e.g., Haskell et al., 1997; Anderson, 2001; Gennard, 2007; Haskell, 2007; Haskell and Williams, 2008; Sharanowski et al., 2008; Byrd and Castner, 2010; Forbes and Dadour, 2010; Higley and Haskell, 2010; Blair et al. 2012; Pastula and Merritt, 2012), with most of these studies concentrating on PMI or TSD estimates. According to Haskell et al. (1997) the amount of arthropod activity associated with decomposition is directly proportional to the temperature; the cooler the climate the less insects-the warmer the climate the more insects. In addition, in warm weather, one of the biggest decomposition factors is insect activity. The height of maggot activity is associated with putrefaction which is usually in the early stage of decomposition.
According to Byrd (2011) through the proper analysis of entomological evidence, the forensic entomologist can assist medico-legal personnel in the determination of PMI. “Most frequently, the entomologic-based time frame is the minimum portion of the PMI, and it is determined by a minimum time since insect development “(Byrd, 2011, p. 3). By using the known developmental rates for insect species that are attracted to decomposing tissues, this time period is calculated. “Therefore, the minimum PMI can be estimated through the knowledge of insect activity and development throughout the decomposition process” (Byrd, 2011, p. 3).

Amendt et al. (2005) discusses a method for estimating PMI, and it consists of 2 main procedures:

“1) During the early postmortem period, the estimate is based on a direct age assessment of the oldest individuals that have developed on the cadaver (minimum PMI) and, 2) During the late postmortem period, the estimate is based on the composition of the arthropod community as it relates to expected successional patterns” (p. 95).

Gennard (2007) states that there is a relationship between the rate of insect growth from the oviposition or larviposition stage to the adult stage, and temperature. “This is because growth and development through the various life stages has a cost in terms of a ‘physiological development energy budget,’ and this budget can be expressed in thermal units call degree days (DD) or degree hours (DH)” (Gennard, 2007, p. 118).

Although all researchers seem to agree that the process of decomposition consists of a series of transmogrifying events after death, they disagree on how to reach an accurate TSD estimation. Decomposition is variable in degree and length of time. Many factors affect cadaver decomposition including temperature and humidity. Temperature and humidity also affect insect activity as well as their rate of development, which in turn is dependent on season of the year, location of cadaver, as well as other factors. Therefore, when measuring TSD, not only does
passage of time need to be accounted for but environmental variables relevant to both place and
time need to be evaluated (Fitzgerald and Oxenham, 2009, p. 38).

Studies by Sharanowski et al. (2008), Rodriguez and Bass (1983), and Shean et al. (1993)
agree that temperature and humidity are two of the most important factors in estimating PMI,
especially when insect activity is high. When the insect activity is low, due to several factors
including cold temperatures-estimating PMI using insects can be problematic if not impossible.
They also agree that knowing what species of insects feed on carrion during various seasons is
crucial. It is, therefore, important to gather forensically relevant entomological data from all 4
season in all biogeoclimatic regions in order to better account for the stages and rates of
decomposition. The correlation between the number of carrion insects and rate of decomposition
demonstrates that insects are a significant factor in cadaver decomposition (Rodriguez and Bass,
1983; Shean et al., 1993; Haskell and Williams, 2008; Sharanowski et al., 2008).

Entomologists utilize the blow fly life cycle to attempt to estimate a TSD or PMI by
establishing the time since colonization of the insects that arrived on the scene, during the first
wave of succession. The entomological PMI represents the time between when the body was
discovered and when the insects began their development. According to Nabity et al. (2006),

The PMI calculated from ADD represents the shortest time frame possible because
intrinsic and extrinsic factors only slow, rather than increase, developmental rate.
Subsequently variation is assumed into the final PMI and adjusted for scene context (e.g.,
weather phenomena and wrapped body) (p. 1284).

The PMI can be estimated over periods of weeks in warm weather and over periods of weeks
to months in cold weather. This is why PMI from insect development must be considered an
estimate and not an absolute time frame. “By incorrectly calculating ADD in violation of the
model assumptions, bias is introduced into the estimate of the initial PMI based on ADD”
(Nabity et al., 2006, p. 1284). To use larval development in estimating PMI, accurate information on the development of individual species is essential. Currently, much of the available information comes from relatively few studies, often with limited data sets (Byrd and Allen, 2001, Higley and Haskell, 2001). An important issue is the assumption that oviposition occurs shortly after death; yet, various circumstances (such as diurnal versus nocturnal oviposition patterns, access to a body, or cold temperatures) may delay oviposition. If a body is in an enclosed location, such as a burial, or is wrapped tightly with some kind of material, colonization may be delayed (Goff, 1993). Huntington and Higley (2008) give an example of how to calculate degree days to arrive at PMI. The first step is to determine the base temperature (the temperature where zero development is predicted) of the blow fly that is going to be utilized. The second step is to determine the average daily temperature at the death scene. The second step is to subtract the base temperature of the fly from the daily average temperature. The difference in temperature equals the amount of degree days needed for a 24 hour period. For example, $20^\circ C - 10^\circ C = 10$ degree days. If, for example, the blow fly needs 400 accumulated degree days to go from the egg to the pupal stage-$400/10$ (degree days) $= PMI$ of 40 days.

A study by Barnes (2000) conducted in Montana from June 1999 through December 1999, at the Lubrecht Experimental Forest examined the decomposition process utilizing entomological data from 1 burned and 1 unburned pig ($Sus$ $scrofa$) cadavers placed in partial shade on the ground surface. He hypothesized that insect activity would be distinguishable in a mixed urban/rural and rural area on the cadavers. The burned cadaver, according to Barnes (2000) remained in the fresh stage for 1 day, the bloated stage for 7 days, the decay stage for 4 days, the advanced decay stage for 23 days, and the remains stage for 186 days. Barnes (2000) found that the species $Phormia$ $regina$ (black blow fly) and $Lucilia$ $illustris$ (green bottle fly) were the
dominant species of the order Diptera on both carcasses. Additionally, he found that the *Phormia regina* were present during the duration of the study. Barnes (2000) found that there were similarities in the waves and rates of succession for arthropods in a study by Dillon (1997) in British Columbia, Canada. The exception was that the most abundant species of Diptera in Dillon’s (1997) study were *P. regina* (black blow fly) and *Protophormia terraenovae* (holarctic blow fly). Barnes (2000) observed adult *P. terraenovae* through the duration of the burned cadaver, but only observed this species on the unburned cadaver through the first 13 days of the study. Dillon’s (1997) research study found no difference between types of Calliphoridae (blow fly) species in the micro-environments of shade versus sun. Dillon (1997) also found that clothed cadavers experienced longer stages of decomposition than unclothed cadavers. Both Barnes (2000) and Dillon (1997) placed their cadavers in forested areas. The Barnes (2000) study serves as an entomological baseline study for the decomposition process in Montana.

Hall et al. (2012) reveals that a biological clock begins ticking as soon as the first blow fly deposits her eggs on a body. Using studies developed to study the colonization and development of the blow flies helps researchers estimate the PMI over a period of weeks in the summer and as many as a few months in cooler months. Insect succession is subject to local and seasonal variations. A PMI can be estimated by measuring the particular instar of the oldest blow fly, and then checking the databases of development to estimate how long it would take for the larva to develop to reach the life stage at the temperatures estimated for the death scene (Hall et al., 2012). One of the problems with this method is that the metabolic temperature of the larva in the maggot mass can be considerably higher than the temperatures estimated at the scene.
Vertebrate Scavenging

Several studies (Haglund, 1997a, 1997b; Klippel and Synstelien, 2007; Suckling, 2011; Alfieri et al., 2012; Blair et al., 2012; Pharr, 2012) have been conducted on the effects of scavenging on exposed cadavers. Scavenging can occur indoors as well as outdoors. A corpse exposed indoors can be subject to scavenging by domesticated pets such as cats, dogs, and birds. A corpse exposed outdoors can be subjected to predation by various kinds of vertebrate scavengers.

According to McKeown et al. (2011), a greater awareness of large carnivore scavenging in the Rocky Mountains of Montana needs to be acknowledged and understood in order come to an accurate PMI. Mummification is commonplace during early decomposition, and the remains can become static without the aid of scavenging. The occurrence of scavenging needs to be researched further in order to assist forensic investigators in reaching an accurate TSD estimation.

Another study conducted in Montana by Bankaitis (2012) looked at scavenging by captive wolves in a 10-acre fenced-in area. In the study, 1 pig (Sus scrofa) cadaver was placed within the enclosure that housed several tame wolves. The cadaver was placed in November and only studied for 2 weeks. In addition, the owners of the wolves would feed the wolves (e.g. turkeys for Thanksgiving); therefore, there is some question whether or not the wolves were scavenging the pig carcass out of necessity or simply to provide themselves with a supplementary meal. The researcher returned to the site after 2 months and recovered only 4 pig bones. No data was provided from the end of the 2 week observational study until the return to the site, 2 months later. Bankaitis (2012) hypothesized that scavenging patterns from large carnivores can be
distinguished from one another based on the behavior of the carnivore. She determined that bears and pumas are a wolf pack’s strongest competition for food, and their patterns of scavenging bear strong similarities to that of wolves that cannot be distinguished based on this study; therefore, she could not reject her null hypothesis.

According to Rodriguez (1997) large carnivores, especially wolves, coyotes, and domestic dogs are known to feed on the cadaver throughout the postmortem period, including through the skeletonization stage, but dispersal and removal of skeletal elements by coyotes and wolves is normally less than scavenging and dispersal of skeletal elements by domestic dogs. Pokines and Tersigni-Tarrant (2013) reveal that movement of bone is a normal process of carnivore scavenging, as it cuts down on competition by removing the remains from the scene. Additionally, Pokines and Tersigni-Tarrant (2013) report that damage to the skeleton tends to follow the same pattern with the easiest accessible portion scavenged first and the remains of the skeleton scavenged later. The throat is often scavenged on human remains, which could be due to clothing impeding the scavenging (Pokines and Tersigni-Tarrant, 2013, p. 327; Haglund, 1997a). Haglund (1997a) also note that in warmer weather, scavenger-assisted disarticulation is in “competition” with other disarticulating influences such as natural decomposition and insect scavenging (p. 372).

In a longitudinal study by Suckling (2011), collection of scavenging data was allowed. The scavenged cadavers in the abovementioned study had significantly lower ADD to reach major decomposition stages than protected cadavers. Although insect scavenging in certain areas has a huge impact on cadaver decomposition and biomass loss, terrestrial and avian scavenging can also have a huge impact on the TSD estimation and ADD. According to Suckling (2011), decomposition studies need to consider scavenger species and their environments in order to
understand rates and processes of decomposition. Her study emphasizes that insect and vertebrate scavengers significantly accelerate decomposition. During Suckling’s study (2011) she notes how difficult it was to keep the avian scavengers away from the cadavers. Smaller fencing was eventually utilized to prevent the access of avian scavengers. The difficulty in keeping the avian scavengers away from cadavers calls into question whether it is practical to control for scavengers. Instead, the influence of scavengers on decomposition rates needs to be incorporated into decomposition and taphonomic studies in order to come to an unbiased and objective estimate of PMI. Vertebrate scavenging is one of the most meaningful causes of postmortem trauma in an outdoor setting and can greatly alter the estimation of PMI.

Willey and Snyder (1989) reported that nearly 78% of the human skeletal collection at the University of Tennessee demonstrated evidence of scavenging. According to DeVault et al. (2003) scavengers can consume from 35-75% of the cadavers in terrestrial ecosystems, and when entomology and microbes are less active (e.g. during winter months), scavenger success can approach 100%. Small cadavers can be carried away in their entirety, and consumed ex situ; while large cadavers tend to be consumed in situ (Carter and Tibbett, 2008).

Although large carnivores are responsible for decomposition and disarticulation of cadavers, the current study focuses on avian scavenging. According to Rodriguez (1997), a cadaver exposed to an outdoor setting can be subject to depredation by vultures and crows during the later stages of decomposition. According to France et al. (1997), birds are often the first vertebrate scavengers on the scene of surface burials and will continue to visit the cadaver throughout the decomposition process. According to Bass (1997) crows and even buzzards have been observed at the University of Tennessee Anthropology Research Facility (ARF), but they do not seem to be a major contributing factor to human decomposition rates in Tennessee, with
some exceptions. Nawrocki (2009) notes that open exposure to cadavers in agricultural fields can discourage wild canids but attract vultures and other avian scavengers. These scavengers have highly developed visual and olfactory abilities, and can locate cadavers using these heightened senses.

Other studies (McKinnerney, 1978; Reeves, 2009; Pharr, 2012; Spradley et al., 2011) have focused on avian scavenging with particular emphasis on vulture scavenging. The accelerated rate of decomposition from avian scavenging is significant in interpreting taphonomic events and determining an accurate PMI. Many errors have been made in estimating PMI or TSD because avian scavenging tends to occur early in the decomposition process. As in other processes of decomposition, scavenging can occur early in the decomposition process or take place later in the decomposition process.

In Reeves (2009) from July through September 2007, 3 pig (Sus scrofa) cadavers were placed on the ground surface at the Freeman Ranch, in Texas. A fence prevented terrestrial scavenging, but allowed avian scavenging. A 4th control pig was placed in an enclosure, preventing all scavenging. American black vultures (Coragyps atratus) and turkey vultures (Cathartes aura) waited approximately 24 hours before beginning to scavenge the cadavers, but completely scavenged-to the point of skeletonization-the cadavers in 3 to 27 hours of feeding. Consequently, this increased the decomposition process. Reeves (2009) reveals that PMI estimates need to consider the effects of avian scavenging and that death investigators need to understand the effects of all scavenger species within the environment where the cadaver has been discovered. According to Reeves (2009), as avian scavengers continue to prosper and humans encroach on their habitat, contact by avian scavengers on human cadavers will be of great forensic importance and will likely increase in frequency.
A study by McKinstry and Knight (1993) discusses the advantages to individual avian species feeding in groups. In parts of the American West an avian-scavenging guild exists where Bald Eagles (*Haliaeetus leucocephalus*), Common Ravens (*Corvus corax*), and Black-billed Magpies (*Pica hudsonia*) feed in groups at carrion during the winter. The current research observes the facultative Black-billed Magpie as the subordinate avian guild member. According to Selva and Fortuna (2007) in spite of playing a crucial role in food webs by contributing to nutrient recycling and community stability, the phenomena of widespread scavenging by vertebrate communities is rarely accounted for. Of interest in the study is the observation that facultative scavenging is not randomly assembled, but instead, highly nested. “Nested patterns in scavenger communities appear to be promoted by the high diversity in carrion resources and consumers, the differential predictability of the ungulate carcass types and stressful environmental conditions” (Selva and Fortuna, 2007, p. 2).

According to Ubelaker and Scammell (1992), vertebrate scavenging is one of the most frequent sources of skeletal modification and alterations in murder cases, but it can be one of the most frustrating for inexperienced investigators. Often scavenging modifications can be confused with sharp force trauma, which can lead the investigator to error in determining the cause of death.
Chapter 3: MATERIALS AND METHODS

In order to examine the decomposition processes of pig (Sus scrofa) cadavers in western Montana including the micro-environments of full sun versus full shade as well as the effects of avian scavenging, a research facility was established on a ranch just outside of the city limits. Two enclosures were erected to accommodate 3 test specimens (Sus scrofa 1, Sus scrofa 2, and Sus scrofa Control, hereafter referred to as SS1, SS2, and SSC respectively.) Both SS1 and SS2 were placed in separate enclosures on 8/1/2011 and removed on 8/1/2012. Enclosure 1 allowed for all climatological and environmental exposure to SS1. Enclosure 2 was covered with the same hardware cloth that covered Enclosure 1. In addition to the hardware cloth, Enclosure 2 was wrapped with a landscape fabric rated to block 90% of the ultraviolet (UV) rays and also offered protection from many environmental and climatological elements. The door of Enclosure 2 was not covered with the landscape fabric, which allowed limited access by small avian and terrestrial scavenging. SSC was placed in Enclosure 1 which originally accommodated SS1, on 8/1/2012 and removed as soon as the remains had reached the mummification/dry stage and the second generation of Diptera (flies) had hatched on 8/20/2012. Before SSC was placed, Enclosure 2 was wrapped with an additional fabric that consisted of 2.54cm x 2.54cm holes that prevented all avian and terrestrial scavenging, but allowed for climatological and environmental elements to act upon SSC.

During the active stages of decomposition, the facility was visited 2 times per day at approximately 7:00 AM and 4:00 PM. When the specimens had reached an advanced level of decay, the facility was visited once a day, at approximately 4:00 PM for a month. Once the specimens had reached the dry/remains stage of decay, the facility was visited less frequently-with weather permitting. During each facility visit, the following data was taken and documented
on individual data collection sheets: meteorological data using Thermadata loggers placed within
the enclosure and calibrated with the Missoula International Airport’s weather data system; soil
and vegetation changes; ecological, avian, and faunal activity; decomposition stages of each
specimen; entomological activity; odor of each specimen; information from site photographs,
and once a week time-lapse photos from a Day 6 Plotwatcher camera were downloaded and
relevant information was recorded. Entomological specimens were collected, preserved, and sent
to Dr. Ralph E. Williams, for identification and to determine which genus and species of Diptera
were most abundant in order to produce a PMI estimate. Samples of soil from inside Enclosure 1
and Enclosure 2 were taken and sent to Microvision Northwest Forensic Consulting for
examination of the soil profile to check for acidity of soil, organic and inorganic materials, and
other materials that would affect decomposition rates on the research specimens.

Several hypotheses are posited for this thesis. The first hypothesis is predicated on the
supposition that cadavers that are placed outdoors in the hot, semi-arid environment of western
Montana, in August will mummify rather than advance to the skeletonization stage without the
aid of scavengers (Parsons, 2009; McKeown et al. 2011). The second hypothesis is predicated on
the supposition that the accumulated degree day (ADD) formula developed by Megyesi et al.
(2005) to estimate the time since death (TSD) or postmortem interval (PMI) using the total body
scores (TBS) will not work in Montana as most cadavers will either reach stasis in the form of
mummification in a short period of time (8-15 days) in the summer, or become scavenged; this is
based on previous research by Parsons (2009) and Dudzik (2009). The third hypothesis is
predicated on the supposition that the PMI estimate from Vass (2011) will not work in this study,
due in part to the rapid onset of mummification that occurs in Montana and the fact that
decomposition percentages are too subjective to give an accurate estimate of PM. The fourth
hypothesis is predicated on the supposition that the most accurate PMI estimate will come from the entomological evidence; specifically on the life cycle of the *P. regina* blow fly, which is the most abundant blow fly identified in this study. The final hypothesis is predicated on the supposition that the specimen that is placed in the full shade enclosure will decompose more slowly than the specimen placed in the full sun enclosure.

**Research Area**

The research site was 3.54km off of Whippoorwill Road, and just 1.61km away from the Missoula International Airport with a latitude/longitude of 46°54’21.22”N 114°5’57.62”W. The elevation at the site is 970.18m. The site is located on a ranch that is mainly used to raise cattle and grow alfalfa crops. The research site is located at least 3.22km from any adjacent private properties. Accessibility to the site depends upon how much moisture the site receives. The soil is considered Grassvalley silty clay loam (Schneck, 2012). Grassvalley soils are used for irrigated and dry land crops and as pastureland and rangeland. The potential native vegetation is Bluebunch Wheatgrass, Rough Fescue, Needle-and-Thread Grass, and Prairie Junegrass. Soils are well drained with slow to rapid runoff and very slow permeability (Appendix B). Grassvalley soils are of small extent in valleys of western Montana. When too much moisture accumulated, the site was not accessible as the sandy soils turned into a sticky clay consistency. Additionally, when the snowfall was too heavy, access was impossible. In those circumstances, the time-lapsed cameras and data loggers recorded all pertinent information and data.

During hay season, the site was unavailable to the cattle for grazing. However, after hay season had ceased, the cattle were allowed onto the site to graze outside the enclosures. The site was located on Missoula Airport land but leased by the rancher. The airport authority, ranch owner, and ranch manager all granted permission for the research project.
The research site is on a hill, in an open hay field. Approximately 150 yards from the site is a small ravine that contains several native evergreen trees. With the exception of the trees within the ravine, there is no shade at the site (Figure 1).

![Research area](image)

**Figure 1: Research area**

This site was chosen for several reasons. The first reason for selecting this site was for access and convenience for data collection. Decomposition research by Parsons (2009), Dudzik (2009), Gonder (2007), Barnes (2000), and Wagster (2007) used research sites within the Lubrecht Experimental Forest, 48.28km east of the University of Montana campus. The Lubrecht Experimental Forest consists of 28,000 acres of zoned and managed land for recreation, research, conservation, and range management. The Lubrecht research site is located along an unimproved secondary road that is approximately 6.24km from the Lubrecht Experimental Forest.
headquarters off of Highway 200. The site of the current study is located in Missoula, Montana and only 1.61km from the Missoula International Airport. The second reason for choosing this research site was for the elevation. The elevation at the previous research site at the Lubrecht Experimental Forest is 1310.6m. The new research site is located at an elevation of 975.36m which is the mean elevation for the state of Montana. Human remains could be found at either elevation, so collecting data for several elevations will be helpful in studying soft tissue decomposition and postmortem changes.

Native birds observed and photographed within the research area included Black-billed Magpies (*Pica hudsonia*) (Figure 2), American Crows (*Corvus brachyrhynchos*), Northern Ravens (*Corvus cryptoleucus*), Red-tailed Hawks (*Buteo jamaicensis*) (Figure 3), Turkey Vultures (*Cathartes aura*) (Figure 4), Bald Eagles (*Haliaeetus leucocephalus*), Golden Eagles (*Aquila chrysaetos*), American Kestrels (*Falco sparverius*), Great Horned Owls (*Bubo virginianus*), Barn Swallows (*Hirundo rustica*), numerous English Sparrows (*Passer domesticus*), as well as other unidentified species.

Native fauna observed in the area include White-tailed deer (*Odocoileus virginianus*) (Figure 5), coyotes (*Canis latrans*), badgers (*Taxidea taxus*), deer mice (*Peromyscus maniculatus*), ermine or stoat (*Mustela erminea*), and others. Domestic cows and dogs were also observed in the area. Photographs were taken when the opportunity arose. All photographs presented were taken by the researcher.
Figure 2: Black-billed Magpies

Figure 3: Red-tailed Hawk
Figure 4: Turkey vulture

Figure 5: White tail deer
**Research Study Enclosures**

Two enclosures were assembled on the site to hold the 3 research subjects. Both enclosures were manufactured as dog kennels for medium to large dogs. Each enclosure measured 1.83m x 3.05m x 1.83m. Both enclosures had gates on their north end, and could be locked to prevent tampering. Hardware cloth, similar to the material from the sides of the enclosure, was placed and secured over the top of the enclosures to prevent large avian or mammalian scavenging. Scavenging of small animals and birds was allowed, only if they could squeeze through the material covering the enclosures. Each enclosure was staked to the ground using corner posts on all four corners, and one additional stake on each side of the enclosure along the 3.05m sides. Wire was used to secure the posts to the enclosures. The enclosures were placed 7.62m away from each other. Enclosure 1 was in full sunlight, unprotected from the elements, and had 9cm x 9cm holes which allowed small avian and terrestrial scavengers to access SS1. Enclosure 2 was wrapped with a fabric that was rated to block 90% of the ultraviolet (UV) rays which provided considerable protection from the ecological and environmental elements, and prevented most avian and terrestrial scavengers from gaining access to SS2 (Figure 6). Enclosure 1 was modified to accommodate SSC after SS1 had been removed. The modification consisted of a fencing material placed over the entire enclosure with 2.54cm x 2.54cm perforations, to prevent all scavenging (Figure 7).

In several of the studies at Lubrecht Experimental Forest, an electrified fence was placed around the research enclosures. The enclosures in the current research were sturdy enough that an electrified fence was not necessary, as nothing short of a tractor could budge the enclosures.
Figure 6: Enclosures for SS1 and SS2

Figure 7: Enclosure with additional mesh covering, with holes measuring 2.54cm x 2.54 cm for SSC
Within each enclosure, a Thermadata logger was mounted to the interior wall to record ambient temperature and humidity. An additional Thermadata logger was placed in each enclosure to record temperature data between the research specimen and the ground underneath the specimen. Also included in each enclosure was a Day6 Plot Watcher Time-Lapse camera set to take still photos at 10 second intervals from early light until sundown. Mounted inside of enclosure number two was an additional Day6 Plot Watcher Time-lapse camera positioned to record photos of enclosure number one. A cloth measuring tape was also placed inside each enclosure, underneath the specimens, to measure bloat of each specimen.

**Research Specimens**

For the current study, 3 pig (*Sus scrofa*) cadavers were utilized as proxies for human cadavers. Pigs are analogous to humans because of their comparable skin thickness, body hair instead of fur, and similar gut morphology. Numerous studies (Payne, 1965; Dillon, 1997; Barnes, 2000; Dudzik, 2009; Parsons, 2009, and Bankaitis, 2012) have utilized pigs as human proxies.

SS1 was acquired from rancher, Hans McPhearson, in Stevensville, Montana and euthanized prior to purchase at Hamilton Pack by the owner in Hamilton, Montana using a .22 caliber gun placed behind the left ear. Time of death was approximately 2:00 PM on 8/1/2011. SS1 weighed 78kg at the time of death. SS1 was wrapped tightly with clear plastic wrap and placed in an open trailer, for the drive from Hamilton Pack to the research site in Missoula, Montana. The clear plastic wrap was utilized to prevent premature insect activity, before placement at the research site. SS1 was placed in Enclosure 1 at 5:15 PM on 8/1/2011, shortly after being delivered to the research facility. SS1 was placed on its left side, on the surface of the ground. Girth was measured at that time as 105 centimeters at the largest part of the belly (Figure 8).
Meteorological conditions on the day and time of placement were as follows: temperature 32°C (90° F), dew point 12°C (54°F), relative humidity 37%, visibility 16.09 km, wind 16.09 km, cloud cover 40%, and just a trace of precipitation. The Thermadata logger was originally placed in the anus of SS1, but during the process of colliquative putrefaction, the logger was pushed out with the entrails. The data logger was then placed between SS1 and the ground underneath it. Photographs were taken and information was documented on a data sheet. A few blow flies were present within 5 minutes of placement. Odor was recorded as barnyard/feces.

**Figure 8: SS1. Day 1: 8/1/2011**

SS2 was also acquired from rancher, Hans McPhearson, in Stevensville, Montana and euthanized prior to purchase at Hamilton Pack by the owner in Hamilton, Montana using a .22 caliber gun placed behind the left ear. Time of death was approximately 2:00 PM on 8/1/2011.
SS2 weighed 63kg at the time of death. SS2 was wrapped tightly with clear plastic wrap and placed in an open trailer, for the drive from Hamilton Pack to the research site in Missoula, Montana. The clear plastic wrap was utilized to prevent premature insect activity, before placement. SS2 was placed in enclosure two at 5:31 PM on 8/1/2011, shortly after being delivered to the research facility. SS2 was placed on its left side, on the surface of the ground. Girth was measured at that time as 103 centimeters at the largest part of the belly (Figure 9).

Meteorological conditions on the day and time of placement were as follows: temperature 32°C (90°F), dew point 12°C (54°F), relative humidity 37%, visibility 16.09km, wind 16.09km, cloud cover 40%, and just a trace of precipitation. The Thermadata logger was originally placed in the anus of SS2, but during the process of colliquative putrefaction, the logger was pushed out with the entrails. The data logger was then placed between SS2 and the ground underneath. Photographs were taken and information was recorded on a data sheet. A few blow flies were present within five minutes of placement. The odor was recorded as barnyard/feces.
SSC was acquired from Rick’s Kustom Kut in Arlee, Montana on 8/1/2012. It was euthanized prior to purchase by the owner of Rick’s Kustom Kut at 1:15 PM in Arlee with a .22 caliber gun placed behind the left ear. It was wrapped tightly in plastic wrap to prevent premature entomological activity before placement at the research site. SSC was transported to Missoula, Montana by Rick of Rick’s Kustom Kut. SSC was retrieved by the researcher at the CostCo parking lot at 4:00 PM; thereafter, delivered to the research facility and placed in Enclosure 1 at 4:20 PM, on its left side on the ground surface. Photographs were taken and documentation took place at that time. SSC weighed 36kg at the time of death. Girth was measured at 90.17cm at the largest part of the belly (Figure 10). A few blow flies were present within five minutes of placement. The odor was recorded as barnyard/feces. The Thermadata logger was placed between SSC and the ground underneath it.
Data Collection Protocol

Data were observed on SS1, SS2, and SSC during all site visits. The data included day and time of visit, stages of decomposition, information from digital photographs, visual observations, odor, bloat, entomological activity and collection procedures, climatological and temperature information, Thermadata logger readings, environmental details, and any additional information that needed to be recorded during the site visit.

Documentation of Site and Specimen Conditions

Upon reaching the ranch for site visits, faunal and avian visualization commenced. If any unusual environmental conditions (e.g., wildlife, avian activity, unusual soil conditions, heavy airport activity, livestock, and ranch machinery) were present on the ranch or near the research
enclosures, photographs would be taken with a Nikon 5100 digital camera and notes were transcribed onto individual data recording sheets.

At the research site, and during each visit, the same series of photographs was taken of each specimen from the north entrance, at the head of each specimen, at the ventral side of each specimen, over the top of each specimen, at the tail end of each specimen, and then any additional photos deemed necessary. During periods of heavy insect activity, video was also taken using the Nikon 5100 camera. After returning home from each site visit, all photographs from the site visit were downloaded to separate specimen files on a HP laptop computer, labeled SS1, SS2, and SSC respectively. Photographs were also dated and time-stamped.

The battery operated Day6 Plot Watcher Time-Lapsed camera placed on the inside northeast corner of each enclosure took still photographs of each specimen every 10 seconds between sunrise to sunset. In March 2011, an additional Day6 Plot Watcher Time-Lapsed camera was placed inside the enclosure for SS2 and positioned to take photographs of the SS1 enclosure. This was done to photograph the avian scavenging taking place at the SS1 enclosure by Black-billed Magpies and other scavengers. During the first 3 months of data recording, the data from the time-lapse cameras were downloaded into separate files on a Game Finder program on the HP computer every Monday. After the first 3 months, the data from the time-lapse cameras were downloaded into separate files on a Game Finder program on the HP computer during each site visit. Upon returning home from the site visit, files were viewed and dated. If anything unusual happened, the individual photograph was saved to the specific file to be used at a future date.

During each site visit, notes were recorded on individual data sheets. In the visual observation section, any new or unusual information was noted along with any observation of “no change.” Visual observations included those of specimens as well as the surrounding environment. Color
of specimen was noted. The purge around the specimens, referred to as the cadaver decomposition island (CDI), was assessed and noted. Vegetation changes around specimens were recorded. Condensation was noted, as well as any other signs of moisture from dew, rain, snow, or other sources. Insect activity was observed and documented. Forensically relevant insects were collected.

During each site visit, a total body score (TBS) according to the method used in Megyesi et al. (2005) was recorded for each specimen. Megyesi et al. (2005) uses a sequential scoring system so that the summary decomposition scores reflect the total accumulated decomposition that has taken place on three separate segments of the body. These segments are the head and neck, the trunk, and the limbs. After all of the body segments have been scored, a TBS is calculated.

Tables 1, 2, and 3 show the categories and stages of decomposition for the head, neck, trunk, and limbs from Megyesi et al. (2005). These tables will be used to score the specimens in the current research.
Table 1: Categories and stages of decomposition for the head and neck from Megyesi et al. (2005).

**Fresh**

(1pt) 1. Fresh, no discoloration

**Early Decomposition**

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

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

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

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

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

**Advanced Decomposition**

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

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

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

**Skeletonization**

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

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

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

(13pts) 4. Dry bone.
Table 2: Categories and stages of decomposition for the trunk from Megyesi et al. (2005).

Fresh

(1pt) 1. Fresh, no discoloration

Early Decomposition

(2pts) 1. Pink-white appearance with skin slippage and marbling present.

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

(4pts) 3. Bloating with green discoloration and purging of decomposition fluids.

(5pts) 4. Postbloating following release of the abdominal gases, with discoloration changing from green to black.

Advanced Decomposition

(6pts) 1. Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity.

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

(8pts) 3. Mummification with bone exposure of less than one half that of the area being scored.

Skeletonization

(9pts) 1. Bones with decomposed tissue, sometimes with body fluids and grease still present.

(10pts) 2. Bones with desiccated or mummified tissue covering less than one half of the area being scored.

(11pts) 3. Bones largely dry, but retaining some grease.

(12pts) 4. Dry bone.
Table 3: Categories and stages of decomposition for the limbs from Megyesi et al. (2005).

**Fresh**

(1pt) 1. Fresh, no discoloration

**Early Decomposition**

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

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

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

(5pts) 4. Brown to black discoloration of flesh, skin having a leathery appearance.

**Advanced Decomposition**

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

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

**Skeletonization**

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

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

(10pts) 3. Dry bone.

**Stages of Decomposition**

Cadaver decomposition is a highly variable process that is dependent upon many factors. Some of the factors include temperature, climate, humidity, vegetation, soil environment, intricate chemical processes, water, elevation, insect and carnivore activity, and other factors. Previous studies by Rodriguez and Bass (1983), Bass (1997), Galloway (1997), Vass et al.,
(2002), Megeysi et al., (2005), Marks et al., (2009), Clark et al., (2011), Forbes and Dadour (2011) and others have sought to classify the processes of cadaver decomposition into very specific stages. These stages have always been dubious since there is usually not a clear line of demarcation between each stage; instead, there is a blending of stages (Vass, 2011). For instance, during 1 stage of decomposition, several characteristics of another stage of decomposition could be present. For this study, even though the specimens exhibited 1 or more stages of decomposition, it was prudent to choose the 1 stage of decomposition that best fit each specimen, and assign that stage of decomposition to the specimen. Some of these stages utilized in various research studies have included fresh, bloated, early decomposition, advanced decomposition, decay, advanced decay, post-decay, dry, mummification, adipocere formation, and skeletonization. For the purposes of this study, the decomposition stages were categorized as 1) fresh, 2) bloat/early decay, 3) active decay, 4) advanced decay, and 5) skeletonization. The criteria and trait listed used to assign each specimen to a stage were adopted from descriptions provided by Galloway et al. (1989), Parsons (2009), and Dudzik (2009). Stages of decomposition were assigned according to characteristics described by previous researchers and applied to each cadaver, on a daily basis.

Additionally, along with the decomposition stages, also noted on the data collection sheets was the presence or absence of lividity, marbling, skin slippage, bloat, hair loss, odor, mummification, and vertebrate or invertebrate scavenging on all specimens. The association between the necrophagous arthropods and vertebrate scavengers at a research site are not well known because few studies have been devoted to assessing rates of decomposition for cadavers without protection from terrestrial and avian scavenging. By excluding vertebrate scavengers from accessing the carrion through the use of cages, forensic anthropologists may inadvertently
bias results when estimating the postmortem interval PMI (Pharr, 2012). In Montana, because of the size of the state and the relatively low population, deaths often go unnoticed or unreported. Consequently, remains may not be recovered immediately. When remains are discovered outdoors after a period of time, they are often disarticulated—most likely due to avian or terrestrial scavenging. Therefore, applying the current methods of PMI to establish time since death will not be appropriate or accurate, as scavenging as a factor of decomposition is excluded from these methods.

Odor of each specimen was recorded on the individual data forms during each site visit. The odor was characterized as either none, barnyard/feces, mild, moldy, musty, strong, putrid, or pungent.

Before each specimen was placed in the enclosure, a metric cloth tape was positioned on the ground inside the enclosure, so as to record degree of bloat. Each specimen was subsequently placed in each enclosure on top of the measurement tape. During each site visit where bloat was apparent, the bloat was recorded on the individual data collection sheet. When bloat was no longer apparent, it was not recorded. The tape measure was located under the largest part of the abdomen of each specimen (Figure 11). Bloat is caused by gases that are generated in the cadaver through metabolism of nutrients by anaerobic bacteria. It is one of the most noticeable events of decomposition because initially the abdomen swells and later the entire body swells up like an air-filled balloon (Gennard, 2007).
Climatological and Temperature Data

Climatological and temperature data are crucial when conducting a research project on decomposition processes as both can drastically affect the rate of decay. Several cold weather climate studies have been conducted (Micozzi, 1986, Komar, 1998). In addition, Dudzik (2009) researched decomposition during the freeze-thaw cycle of a Montana winter. Galloway (1997) conducted a decomposition study for dry climates, while Bass (1997) conducted a decomposition study for warm, moist climates. Specimens will decompose more quickly in high temperatures, and more slowly in cold temperatures. Climatological data is critical for estimating the postmortem interval (PMI) by using entomological evidence (Nabity et al., 2006), as well as other methods by Megyesi et al. (2005) and Vass (2011) described in the literature review chapter. Climatological conditions can also affect the developmental rates of insects as well as
carrion feeding habits in a particular environment or specific geographic location (Haskell and
Williams, 2008). Upon arriving at the site, the following data were recorded:

1. Ambient temperature from the Thermadata logger located on the enclosure gate of each enclosure.
2. Body surface temperature of each specimen by placing a digital thermometer on the skin surface.
3. Ground surface temperature of each specimen by placing a digital thermometer on the ground.
4. Under-body surface temperature from the Thermadata logger located on the west side of each enclosure.
5. Metabolic heat of maggot mass temperature by placing the digital thermometer directly in the middle of the heaviest maggot mass on each specimen.
6. Weather conditions (e.g., percentage of cloud cover, fog, smoke or haze, rain, sleet, snow, wind, relative humidity).

The temperature readings at the site were calibrated with those from the Montana Road Weather System weather station located at the Missoula International Airport in Missoula, Montana. (http://www.wunderground.com/history/airport/KMSO.html). The temperature and humidity in Missoula, Montana, on average, are different than other areas of the state and the country where decomposition studies have been conducted (Appendix C). For example, the average precipitation in Missoula, Montana is 3.81 cm per month, or 35.10 cm per year. Many decomposition studies have been conducted at the Forensic Anthropology Center (FAC) in Knoxville, Tennessee where the average precipitation is 10.21 cm per month or 122.48 cm per year. The average annual temperature in Missoula, Montana is 8˚ C (44.8˚F); while the average annual temperature in Knoxville, Tennessee is 15˚ C (58.4˚F). The above example is one of the main reasons why decomposition data are not consistent within states, from state to state, or from country to country. Repeated studies need to be conducted in different climates in order to establish a more comprehensive data set, in order to arrive at an accurate PMI. A data set from Knoxville, Tennessee, for example, will not fairly represent data for areas of the country where the climate is different.
Within each enclosure 2 Thermadata loggers were placed in order to record data for SS1, SS2, and SSC. One of the 2 Thermadata loggers was placed on the door of the enclosure, on the north side. This data logger was placed at 4 feet above ground in order to receive an accurate ambient air temperature. The same data logger also recorded relative humidity. In addition to the data logger that was placed on the north door of each enclosure, an additional data logger with a metal probe at the end of it, was initially placed in the anus of specimens SS1 and SS2. During the bloat stage, the data loggers that were placed in the anus of SS1 and SS2 were pushed out along with the fecal matter. The data loggers were consequently placed between each specimen and the ground near the area where the intestines and colon are located (Figure 12). Recognizing that the data logger placed in the anus does not remain in place, the second data logger for SSC was immediately placed between the specimen and the ground near the area where the intestines and colon are located. Each Thermadata logger was downloaded into the Thermadata logger program onto the HP computer on every Monday for the first three months, and during each site visit after the first 3 months. Data were printed out and placed in the individual files for each specimen at the end of each month, and also saved on individual files on the computer.
Figure 12: Enclosure showing Thermadata loggers. Yellow arrows are pointing to data loggers.

Environmental Details

During each site visit, environmental details were noted and recorded on the individual data recording forms. These details included wildlife present on and around the ranch or research enclosures, soil and ground conditions, avian activity, livestock activity, unusual activity from the Missoula International Airport which is only a mile away from research area, noise levels, other smells that were not specimen specific, air quality due to forest fires, and any other details that were relevant enough to record. The state of Montana consists of 146,318 miles of area. It would make sense that information from one region in Montana could be very different from another area in a state that is so large. Environment plays a significant role in the decomposition process, and should be noted in all decomposition studies. In the current study, the effect of wrapping 1 of the enclosures with a fabric that blocks 90 percent of the UV rays while leaving
the other enclosure fully exposed to the environmental elements was done to determine how the variation in the micro-environments (full sun versus full shade) would affect the decomposition process. The relationship of the soil and organisms, such as plant communities that surround the cadavers, are an important part of the decomposition process. Edaphic endemics is a term that refers to plants or animals endemic to areas of a specific soil type. Cadaver decomposition normally forms a cadaver decomposition island (CDI). Every CDI produces a hub of activity. Although it represents a small proportion of terrestrial area, it accounts for a large amount of heterotrophic activity within that area. Much of the activity within the CDI helps to recycle of cadaveric materials back into the wider ecosystem. The CDI also receives additional organic and inorganic materials resulting from the activity of scavengers and other predators (Carter et al., 2007, p. 19). An example of the CDI activity, provided by Carter et al. (2007) is displayed below (Figure 13.).
Entomological Activity and Collection Procedures

The following procedures were utilized per recommendation of my committee member, Dr. Ralph E. Williams, and are the proper entomological collection and preservation protocol which are generally applicable to any geographic area. Insect activity was documented and photographed upon arrival at the research site before approaching the enclosure. After approaching each enclosure, additional photographs were taken from the same cardinal points within the enclosure. Along with photographs, short videos were taken with the Nikon 5100 camera and documented. Care was taken to avoid agitating or disturbing insect activity. Dipteran life stages were recorded, such as oviposition, larviposition, adult, 1\textsuperscript{st}, 2\textsuperscript{nd}, or 3\textsuperscript{rd} instar larval stages, pupal stages, and new hatch. Coleopteran life stages were also documented. Close-up photographs were taken of insects, especially if there were too few to collect so as not to interrupt the ovi- or larviposition. It was also important to show where insects were located on
the body before any collection took place (Figures 14-17). Recording this information is important for law enforcement or medico-legal personnel as it can provide them with evidence as to whether the remains were located at the primary, secondary, or tertiary death scene.

After initial documentation had taken place, insect samples were collected according to procedure discussed in Haskell and Williams (2008). The first insects that were collected were the adult flies (Diptera). Once these blow flies were netted with an insect sweep net, they were placed in a wide-mouth plastic specimen cup with a screw top lid or in a vial with a screw top lid filled with ethyl acetate. After collection, the adults were labeled and pinned, then transferred into insect preservation boxes. The same preservation procedure was utilized for collecting beetles (Coleoptera). Diptera (flies) were netted while Coleoptera (beetles) were hand collected or captured with soft forceps, and placed into preservation containers. Labels were placed inside and outside of containers and vials, and on the pin-mounted adults. Pre-printed labels were created based on an example in Gennard (2007), but additional information was written on the labels using only a pencil, as ink disappears in the preservation solution. The pre-printed collection label contained the following information: 1) Teresa White, 2) Missoula, MT, 3) Date, 4) Subject, 5) Time and, 6) Location

Larvae were collected with a spoon, preferably a long-handled spoon, and labeled in the screw top specimen containers the same way the adult Diptera and Coleoptera were labeled (Figure 18). The largest larval specimens were collected, as they would indicate the oldest specimens present for the PMI estimate. A representative sample of at least 50 specimens were collected from each specimen in the area of the body that contained the largest amount and size of specimens, and placed into the killing solution in the preservation containers. Shortly after
collection (generally within 30-50 minutes), the larvae were blanched in boiling water for 20-30 seconds, dried, measured, and photographed (Figure 19). After blanching the larvae, the screw top containers or vials were double-labeled, on the inside and outside, and the larvae were placed inside the container with ethanol for preservation purposes (Figure 20). Before adult emergence, pupae casings were collected from the soil near and under each cadaver and placed in the preservation containers with 90% ethanol soaked cotton balls. After adult emergence, adult flies (Diptera) and beetles (Coleoptera) were collected and pinned according to the previous pinning description (Figure 21). Preserved specimens were sent to Dr. Ralph E. Williams, for identification (Appendix E).

Figure 14: Fly on SSC
Figure 15: Flies and larvae

Figure 16: Necrobia rufipes on SSC
Figure 17: Beetle before collection

Figure 18: Collecting larvae

63
Figure 19: Blanched larva

Figure 20: Collection specimens in preservation solution and vials
Data Analysis

The stage and rate of decomposition can provide details about the PMI or TSD of individuals found deceased. Medico-legal personnel often look to forensic anthropologists to provide them with a prompt and reliable rule of thumb method to approximate the PMI or TSD at a death scene, especially for deaths that are older than 1-2 days.

Vass (2011) developed a formula that gives a fast but rough estimate of PMI when medico-legal personnel are limited in time. This rough estimate of PMI gives the death scene investigator a place to begin their search for answers when a time since death is unknown. The formula that will be utilized in the current study is the formula for aerobic PMI estimation as follows:

$$PMI\ (aerobic) = \frac{1285 \times (decomposition/100)}{0.0103 \times temperature \times humidity}$$
Another method for estimating PMI is from Megyesi et al. (2005). Temperature data were collected from the Missoula Montana International Airport weather station. The data were in the form of daily averages, calculated as the average of the minimum and maximum ambient temperatures for the day. Since the research area is only approximately 1.61km from the airport weather station, no corrections to the data were made. ADD represent heat energy units available to advance the decomposition process. According to Megyesi et al. (2005) “base temperature” represents the temperature when decomposition ceases. For the purpose of this study, $0^\circ$ C is utilized as the base temperature because there is an assumption by Megyesi et al. (2005) and other researchers that temperatures below $0^\circ$ C will severely inhibit the decomposition process. Accumulated degree days (ADDs) were calculated by adding together all average daily temperatures above $0^\circ$ C for all days from the TSD. Any temperatures below $0^\circ$ C were counted as 0 rather than allowing negative values into the ADD method (Appendix A).

The decomposition scores were transformed through a regression equation to predict ADD. According to Megyesi et al. (2005), ADD accounts for approximately 80% of the variation of decomposition that takes into consideration accumulated temperature, not just time. Accumulated degree days are compiled by averaging the high temperature and the low temperature, for the day. The following day, the same procedure is followed, and the average score of the first day is added to the average score of the second day in order to accumulate degree days. The process is continued throughout the course of the research project. Megyesi et al. (2005) argues that the core factor of the decomposition process is temperature, while the other factors are considered to be peripheral factors. In other words, decomposition is not as much a result of time as it is a result of time plus accumulated temperatures throughout the decomposition process, with all other decomposition factors being considered after that.
et al. (2005) uses a sequential scoring system so that the final decomposition scores reflect the total accumulated decomposition that has taken place.

In Megyesi et al. (2005) to estimate the time of death, the TBS from each specimen using the previously-outlined scoring method in Tables 1, 2, and 3, were plugged into the ADD equation from Megyesi et al. (2005). For example, if a TBS of 28.5 on SS1 were plugged into the equation, the resulting number would be 2691.53 ADD that would have been needed for SS1 to reach the stage of decomposition observed (TBS=28.5). After obtaining the ADD from the previously-outlined description, the day of death for SS1 would be the day that 2691.53 ADD was reached (Megyesi et al., 2005, p. 7). The results will reveal whether or not it is appropriate to create a quantitative method to accurately estimate PMI from visual assessment of decomposition in western Montana. The Megyesi et al. (2005) method holds that decomposition stages are quasi-continuous objective variables, but others consider decomposition stages to be more subjective and vulnerable to interobserver error.

The Black-billed Magpie scavenging was not observed by the researcher, but instead was captured by the Day6 PlotWatcher cameras. Thus, the scavenging data presented will be in the form of information extracted from photographs demonstrating the progression of the scavenging. Notes were included on the individual data recording sheets after viewing the time-lapse cameras. The date when the Black-billed Magpies began to scavenge each of the remains was recorded, along with details of how much of the remains were affected. Once the Black-billed Magpies began scavenging SS1, they returned almost daily to feed on the remains until most of the soft tissue was gone. The scavenging on SS2 was more sporadic, and did not begin until a great deal of SS1 had been scavenged of all nutritive tissues. It is opined that the Black-billed Magpies may have been apprehensive about scavenging the remains of SS2 when they
were unable to observe predators because of the wrapped enclosure. SSC was not scavenged by Black-billed Magpies as they could not squeeze through the one inch by one inch openings in the fencing material. Originally, 2 pig (*Sus scrofa*) cadavers were placed; however, Black-billed Magpies gained access to the full sun enclosure through the tiny 9 cm openings of the enclosure which was meant to keep large avian and terrestrial scavengers from accessing the cadavers. After observing the Day6 PlotWatcher cameras, it was apparent that the Black-billed Magpies were squeezing through the fence and accessing the cadaver. Because scavenging is an important factor in soft tissue destruction/loss, the scavenging was allowed to occur. To compensate for the cadaver that had been scavenged by the Black-billed Magpies, a third cadaver was placed in Enclosure 1 after removal of SS1, on 8/1/2012 as a control specimen. In order to prevent scavenging, an additional fabric consisting of 2.54 cm x 2.54 cm squares was placed over the entire enclosure. The new fabric prevented most scavenging, but allowed all of the other factors of decomposition to occur. Scavenging will be discussed in detail later in the chapter.

The entomological identifications were conducted by Dr. Ralph E. Williams, who can assist with the most frequent question asked of a forensic entomologist by a death investigator and that is, “When did the death occur?” Figure (22) demonstrates the basic life cycle of a blow fly.
In this study, a PMI will be estimated using developmental rates of larvae for the most common and largest species of Diptera collected. Table 2 from Nabity et al. (2006, p. 1277) shown in Figure (23) shows ADD to adult development by using average developmental time and selected base temperatures on *P. regina* from Greenberg (1991) and Byrd and Allen (2001). The following table from Kamal (1958) shown in Figure (24) will also be used to determine how many accumulated degree days are required for *P. regina* to advance through their lifecycle using a constant rearing temperature of 26.7°C.
Figure 23: Showing ADD to adult development from Nabity (2006, p. 1282)

| Table 2.  ADD to adult development by using averaged developmental time and selected base temperatures |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Set (°C) | $T_b = 10^\circ C$ | $0^\circ C$ | $(-4^\circ C)$ | $10^\circ C$ | $0^\circ C$ | $(-6^\circ C)$ | $10^\circ C$ | $0^\circ C$ | $(-7.5^\circ C)$ |
|-----------|-----------------|-----------------|------------------|-----------------|
| 10°F      | 145             | 300             | 407              | 193             | 367             | 262              | 203             | 356             | 250              |
| 12°F      | 157             | 356             | 453              | 214             | 356             | 250              | 248             | 356             | 287              |
| 14°F      | 181             | 381             | 406              | 187             | 339             | 438              | 56.7            | 217             | 346              |
| 16°F      | 214             | 356             | 413              | 215             | 356             | 250              | 248             | 210             | 353              |
| 18°F      | 241             | 381             | 409              | 215             | 328             | 405              | 30.9            | 238             | 354              |
| 20°F      | 276             | 398             | 421              | 227             | 350             | 274              | 31.1            | 238             | 354              |
| Avg       | 228             | 390             | 412              | 216             | 353             | 270              | 31.0            | 238             | 354              |
| SD        | 46              | 14              | 12               | 43              | 22              | 14               | 17              | 22              | 9                |

Base temperatures included both absolute and investigator preferred minimums (0 and 10°C) and empirically determined x intercepts (through regression of days$^{-1}$ vs. temperature) from published data. The x-intercept calculated from the temperatures shown is represented by the value in parentheses. Average and standard deviation were calculated using only values within the linear range as determined by the methods.

$^a$ Development times used to calculate ADD are means from Table 8 in Byrd and Allen (2001).

$^b$ The x-intercepts calculated on combined 2001 and 2004 data are generated from Table 1. The difference between x-intercepts in Table 1 and data elsewhere in this article reflects a mathematical artifact from regressing data of similar yet different values. Consequently, x-intercept data here are only valid in the context of comparisons in this table.

$^c$ Development time at this temperature is outside the linear range.

$^d$ As seen in Table 1, one chamber from 2001 registered a rearing-container temp (14.1°C) high enough above set-chamber temperature (10°C) for development to occur all (except ADD$_{10}$). ADD$_{30}$ and ADD$_{50}$ are 74, 46, and 64, respectively. But because this point is within the nonlinear portion ($^c$), it is not used to figure averages.

$^e$ Average of published values from Greenberg (1991). All times are average minimum duration from Table 2, 6, and 7 in Greenberg (1991).

---

Figure 24: Phormia regina lifecycle chart from Kamal (1958, pgs. 261-71.)
Meteorological data was utilized from the Thermadata loggers and the weather station located at the Missoula, Montana International Airport, just 1.60km away from the research site, to establish the accumulated degree-days in order to estimate PMI. Additional pertinent data was entered into Excel spreadsheet, and moved into appropriate programs after compilation in order to present graphs, tables, and statistical analyses.
Chapter 4: RESULTS

Decomposition Observations

The results of the decomposition process are going to be presented including 1) the stages of decomposition, including days spent in each decomposition stage, 2) the variable micro-environments with surface deposition, 3) estimating the postmortem interval (PMI) from Megyesi et al. (2005), Vass (2011), and estimates of PMI using entomological evidence, 4) entomological identification, and 5) vertebrate scavenging. Some of the limitations of this research study were 1) the small sample size, 2) all specimens were placed in August so the initial decomposition stages are limited to the hottest temperatures of the year, 3) enclosures were erected to prevent most terrestrial and avian scavenging, but the Black-billed Magpies were able to squeeze through the small openings, 4) access to the site was limited at times due to inclement weather and ground conditions, and 5) the equipment did not always function correctly.

Days Spent in Each Decomposition Stage

In any decomposition study, it is helpful to determine how long each specimen spends in each stage of decomposition. In this study, all three specimens were delivered to the research site within 2-4 hours of being euthanized. All three specimens were observed to be in between the fresh and bloated stages of decomposition. Each specimen was placed on its left side, and both right hind and front legs were already in rigor mortis, and purge was visible from the mouth, nose, and anus. This observation suggests that the specimens, upon placement, were already advancing from the fresh stage to the bloated stage. This could have been due to the temperature
on the day of placement which was approximately 30°C (90°F). Table 4 provides a summary of the rapid passage from the fresh to the active decomposition stage.

**Table 4: Bloat Chart for SS1, SS2, and SSC from researcher**

<table>
<thead>
<tr>
<th>Date</th>
<th>AM/PM</th>
<th>Bloat CM</th>
<th>Date</th>
<th>AM/PM</th>
<th>Bloat CM</th>
<th>Date</th>
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</tr>
</thead>
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<td>108</td>
<td>8/1/2011</td>
<td>PM</td>
<td>105</td>
<td>8/1/2012</td>
<td>PM</td>
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</tr>
<tr>
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<td>PM</td>
<td>110</td>
<td>8/1/2011</td>
<td>PM</td>
<td>107</td>
<td>8/1/2012</td>
<td>PM</td>
<td>36</td>
</tr>
<tr>
<td>8/2/2011</td>
<td>AM</td>
<td>122.5</td>
<td>8/2/2011</td>
<td>AM</td>
<td>115.5</td>
<td>8/2/2012</td>
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<td>36.5</td>
</tr>
<tr>
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<td>PM</td>
<td>134</td>
<td>8/2/2011</td>
<td>PM</td>
<td>134</td>
<td>8/2/2012</td>
<td>PM</td>
<td>37</td>
</tr>
<tr>
<td>8/3/2011</td>
<td>PM</td>
<td>128.5</td>
<td>8/3/2011</td>
<td>PM</td>
<td>130.5</td>
<td>8/3/2012</td>
<td>PM</td>
<td>38.5</td>
</tr>
<tr>
<td>8/5/2011</td>
<td>AM</td>
<td>109</td>
<td>8/5/2011</td>
<td>AM</td>
<td>125.5</td>
<td>8/5/2012</td>
<td>AM</td>
<td>35.75</td>
</tr>
<tr>
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<td>8/5/2011</td>
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<td>8/5/2012</td>
<td>PM</td>
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</tr>
<tr>
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<td>8/6/2011</td>
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<td>8/7/2011</td>
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<td>90</td>
<td>8/7/2012</td>
<td>PM</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Figure 25: Days in Each Decomposition Stage or Event for SS1, SS2, and SSC**
In the current study, SS1 spent just 1 day in the fresh stage, 5 days in the bloated stage, 5 days in the active decay stage, 32 days in the advanced decay stage, and the duration of the study in the skeletonization stage. SS2 spent 1 day in the fresh stage, 5 days in the bloated stage, 4 days in the active decay stage, from day 8 until the 8th month in the advanced decay stage, and from month 8 until the end of the study in the skeletonization stage. SSC spent 1 day in the fresh stage, 5 days in the bloated stage, 4 days in the active decay stage, and 11 days in the advanced decay stage (Figure 25). Additionally, Figure 25 depicts how quickly each specimen advanced from the fresh stage of decomposition to the advanced stage of decay. The advanced decay stage was reached in no more than 9 days for any of the specimens.

In addition, mummification appears to be a natural event during decomposition in western Montana especially in the hot, summer months. Without exception, all specimens in the current research study underwent mummification rapidly. The event of mummification began between day 7-9 of SS1, between days 9-10 of SS2, and between days 9-11 of SSC. All of these days are approximate days, as there are no true lines of demarcation between stages of events of decay. The mummification caused a decrease in the entomological activity as the dried tissue was not an ideal environment for oviposit or larval feeding. The semi- to arid conditions at the site, along with the relatively hot temperatures, altered the decomposition stages from previous studies in that the decomposition stages quickly advanced from the fresh stage, to the bloated stage, to the early decomposition stage, to the active stage, and then very quickly to the advanced decomposition stage. Due to the mummification event, more time was spent in the advanced decomposition stage than any of the other stages, combined. Exposure outdoors, with high temperatures and low humidity at this site, sped up the decomposition stages.
SS1 began to reach the skeletonization stage when at least one half of the bones were exposed, which was during week 5 of the study. SS2 began to reach the skeletonization stage during month 8 of the study. SSC did not reach the skeletonization stage, as it was only meant to remain in the study long enough to reach the advanced stage of decomposition.

**Aerobic PMI Estimates from Vass (2011)**

Initially, the formula for the Vass (2011) study was applied to research subject SSC. The data from 2 days during the study including decomposition photographs (2 each), recorded temperature, humidity, and the 2 constants (e.g. 1285, 0.0103) employed with the Vass (2011) formula to estimate PMI. Several percentages of decomposition were estimated from 2 separate days from SSC and tested in the equation. The first photograph in this series was taken on day 6 of the decomposition study (Figure 26). The 2nd photography in this series was also taken on day 6 of the decomposition study (Figure 27). The application of the Vass (2011) formulation for PMI estimation provided the following results.

**Figure 26: Specimen SSC Day 6 Decomposition Study**
In order to show how the percentage of decomposition observed by each observer can skew the results of the PMI estimate, 3 contrasting degrees of decomposition have been plugged into the Vass (2011) formula. The 3 decomposition percentages were chosen as fair representations of what observers may believe the cadaver is experiencing. The percentages are 1) 10%, 2) 25%, and 3) 50% respectively. The results of the equation are provided below:

\[
\text{PMI (Aerobic)} = \left\{ \frac{1285 \times (\text{decomposition/100})}{0.0103 \times \text{temperature} \times \text{humidity}} \right\}
\]

\[
\frac{1285(10\% \text{ decomposition/100})}{0.0103 \times 21^\circ \text{C} \times 49.1\% \text{ RH}} = 128.5/10.62 = \textbf{12.10 PMI days at 10\% Decomposition Estimation}
\]

PMI Aerobic = \[1285 \times \text{(decomposition/100)}\]/[0.0103 \times \text{temperature} \times \text{humidity}]

\[
\frac{1285(25\% \text{ decomposition/100})}{0.0103 \times 21^\circ \text{C} \times 49.1\% \text{ RH}} = 321.25/10.62 = \textbf{30.25 PMI days at 25\% Decomposition Estimation}
\]

PMI Aerobic = [1285 x (decomposition/100)]/[0.0103 x temperature x humidity]

\[
\frac{1285(50\% \text{ decomposition/100})}{0.0103 \times 21^\circ \text{C} \times 49.1\% \text{ RH}} = \]

\[
\text{PMI Aerobic} = [1285 x (\text{decomposition/100})]/[0.0103 x \text{temperature} x \text{humidity}]
\]

\[
[1285(50\% \text{ decomposition/100})]/[0.0103 x 21^\circ \text{C} x 49.1\% \text{ RH}] = \]

76
\[
642.5/10.62 = 60.50 \text{ PMI days at 50% Decomposition Estimation}
\]

Applying the formula by Vass (2011) the PMI estimate for specimen SSC on day 6 of decomposition, ranges from 12.20 PMI days to 60.50 PMI days. The actual day of death from the photograph provided was on day 6. The PMI estimates from Vass (20110) using the three percentages reveal that the estimates are higher than the actual day of death by 6-54 days. The 4th photograph in this series was taken on day 9 of the decomposition study (Figure 28). The 5th and final photograph of this series was also taken on day 9 of the decomposition study (Figure 29).

![Figure 28: Specimen SSC Day 9 Decomposition Study](image)

The 3 decomposition percentages shown below were chosen as fair representations of what observers may believe the cadaver is experiencing. The percentages, in this case, are 1) 40%, 2) 65%, and 3) 80% respectively. The results of the equation are provided below:
PMI (Aerobic) = \[\frac{1285 \times \text{decomposition}/100}{0.0103 \times \text{temperature} \times \text{humidity}}\]

\[\frac{1285(40\% \text{ decomposition}/100)}{0.0103 \times 25^0 \text{ (C)} \times 45.45\% \text{ RH}} = 514/11.70 = \text{43.93 PMI days at 40\% Decomposition Estimation}\]

PMI Aerobic = \[\frac{1285 \times \text{decomposition}/100}{0.0103 \times \text{temperature} \times \text{humidity}}\]

\[\frac{1285(65\% \text{ decomposition}/100)}{0.0103 \times 25^0 \text{ (C)} \times 45.45\% \text{ RH}} = 835.25/11.70 = \text{71.39 PMI days at 65\% Decomposition Estimation}\]

PMI Aerobic = \[\frac{1285 \times \text{decomposition}/100}{0.0103 \times \text{temperature} \times \text{humidity}}\]

\[\frac{1285(80\% \text{ decomposition}/100)}{0.0103 \times 25^0 \text{ (C)} \times 45.45\% \text{ RH}} = 1028/11.70 = \text{87.86 PMI days at 80\% Decomposition Estimation}\]

Applying the formula by Vass (2011) the PMI estimate for specimen SSC on day 9 of decomposition, ranges from 43.93 PMI days to 87.86 PMI days. The actual day of death from the photograph provided was on day 9. The PMI estimates from Vass (20110) using the three percentages reveal that the estimates are higher than the actual day of death by 35-79 days.

Both examples show that the Vass (2011) equation for estimating PMI does not accurately represent the PMI of the specimen. There are a number of reasons why this formula does not work well in Montana, but the main reason is due to the subjectivity of determining the percentage of decomposition for the specimen.
Accumulated Degree Days and Total Body Score According to Megyesi et al. (2005)

Below you will find the total body scores (TBSs) for all 3 research specimens (Figure 30).

SS1 scored a 9.5 on day 1 of decomposition. On day 2, SS1 reached a score of 12. On day 3, SS1 reached a score of 14.5. On day 4, SS1 reached a score of 17. On day 5, SS1 reached a score of 20. From day 6-8, SS1 reached a score of 26.5. From day 9 until day 71, SS1 scored a 28.5. From day 81 to day 95, SS1 scored a 29. From day 123 to day 133, SS1 scored a 29.5. From day 139 through day 201, SS1 scored a 30. From day 223 to day 253, SS1 scored a 32, and from day 253 through the duration of the study, SS1 scored a 33.

SS2 scored a 3 on the first day of decomposition. On day 2, SS2 reached a score of 12. On day 3, SS2 reached a score of 12.5. On day 4, SS2 reached a score of 14.5. On day 5 through 7, SS2 reached a score of 17. From day 7 through day 153, SS2 reached a score of 23. From day 153 through the duration of the study, SS2 scored a 29.
161 through day 253, SS2 reached a score of 23.5. From day 291 through day 325, SS2 reached a score of 24, and from day 353 through the duration of the study, SS2 scored a 26.

SSC scored a 3 on the day 1 of decomposition. On day 2, SSC reached a score of 11. On day 3, SSC reached a score of 13. On day 4, SSC reached a score of 14. On day 5, SSC reached a score of 15. On day 6, SSC reached a score of 17. On day 7 through day 8, SSC reached a score of 18. From day 9 until the duration of the study, SSC reached a score of 19.5 (Appendix E).

Cadaver SS1 was placed in the enclosure with no protection. It was the first cadaver to reach mummification, and the most advanced stage of decomposition. SS2 reached mummification approximately 1-2 days later than SS1 and remained at the advanced stage of decomposition until a few Black-billed Magpies gained access to the wrapped enclosure. SSC was the smallest cadaver, and did not reach mummification until the 8th or 9th day of decomposition. SSC only remained at the research site for 20 days, as it was the control pig for the study. It is possible that SSC may have reached a higher TBS score if it had remained at the site for the full year that the other 2 cadavers spent in the decomposition process. It may have also been scavenged by small mice or birds, as one English sparrow was spotted in the enclosure on the time-lapse camera.

Figure 30 shows the difference between the 3 specimens using the TBS and the PMI. As you can see, SS1 has the highest TBS scores within a shorter amount of time. Both SS2 and SSC had similar patterns of TBS, although there was a marked difference in the TBS for SS2 and SSC between day 6 and 7. This could be due to an environmental or climatic factor. Finally, all 3 specimens appear to reach a plateau from day 7 onward until scavenging increased the TBS. The TBS of SSC did not increase, as the specimen was only out for 20 days—just long enough for it to reach mummification and for the pupae to emerge into adults for collection purposes.
Using Total Body Score to Estimate Accumulated Degree Days for Megyesi et al. (2005)

Figure 31 shows the TBS and ADD for SS1, SS2, and SSC. The left side of the figure shows the total body score from the Megyesi et al. (2005) method for estimating PMI. The bottom of the chart shows the accumulated degree days. The colored dots and lines show what each specimen did using the Megyesi et al. (2005) method. As you can see, the total body scores increased very quickly, within zero to 250 ADD, which is between day 1 and day 12 of the current study. The ADD were calculated by averaging each daily temperature, and adding it up in order to accumulate degree days. The total body score is a point scoring system developed by Megyesi et al. (2005) to determine how much of the body has decomposed. The higher the TBS number, the more decomposed the remains are. All three specimens advanced to the mummification stage in less than 12 days or 250 ADD, so the lines and dots go from 3 and up to
30 in that short amount of time. The highest TBS that can be recorded, according to Megyesi et al. (2005) is 35. Specimen SS1 reached a TBS of 33. As you can see, there is a plateau that both SS1 and SS2 reach after 250 ADD. The reason for the plateau is due to the mummification. In addition, the only time when the plateau changed was when the scavenging from the Black-billed Mapgies was significant enough to cause an increase in the decomposition point scoring system. Both SS1 and SS2 experienced a peak around the 2000 ADD point which is equivalent to 273 days. The approximate date of the change is mid-April. Much of the remains from SS1 had been scavenged; consequently, the Black-billed Mapgies began to scavenge SS2 enough that it was evident in the Megyesi et al. (2005) scoring system.

Listed below are Tables 5, 6, and 7 of how the TBS are calculated for all three specimens from day 1 through day 15. The TBS only increased as bone began to show, due to scavenging. The TBS charts for the entirety of the study, from all three specimens, are located in Appendix D.

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Below are the ADD scores for SS1, SS2, SSC, and Case #53 from Missoula Montana which was considered an outlier in the Megyesi et al. (2005), and removed prior to generating the equation.

- SS1 ADD = 2691.53 (7/8/2012); 2303.38 (5/27/2012) to 3079.69 (7/8/2012).

  According to this equation, the error equals the estimated PMI of 7/8/2012 minus the actual day of death of 8/1/2011. The difference is 342 days. This equation was a failure as the standard error is +/- 388.16, which was reached in Missoula, Montana on 8/19/2011. This equation was a failure with the daily average temperature throughout the study of 6.7°C.

- SS2 ADD = 776.25 (9/8/2011); 388.09 (8/19/2011) to 1164.41 (10/2/2011).

  According to this equation, the error equals the estimated PMI of 9/8/2011 minus the
actual day of death of 8/1/2011. The difference is 40 days. This equation was a failure as the standard error is +/- 388.16, which was reached in Missoula, Montana on 8/19/2011, with the daily average temperature throughout the study of 6.7⁰ C.

- SSC ADD = 371.54 (8/18/2012); -16.63 (before placement) to 759.70 (9/7/2012), when the actual TSD was from 9-15 days PMI. This equation was a success as the standard error is +/- 388.16, which was reached in Missoula, Montana on 8/18/2012, with an average daily temperature of 22⁰ C. The only reason why this equation was successful was due to the short exposure time and the high standard deviation. If SSC had been left outdoors longer, the ADD equation would not have been successful as the ADD would not have matched the actual TSD.

- Case #53 from Missoula Montana ADD = 489.78; 101.62 to 877.94, when the actual TSD was 22 days. This equation appears to be a success as it falls between the intervals; however, the body was only exposed outdoors for 21 days-from 10/17/1993 to 11/7/1993. The use of liberal error range of 388.16 was the only reason why this equation was a success. It was, according to Megyesi et al. (2005), an outlier due to other environmental factors specific to Montana that are not directly controlled for in their study.

**Climatological Results**

Decomposition rates in the semi-arid climate of Missoula, Montana during the summer are similar to those observed in other similar semi-arid climates, with a high rate of entomological activity, accelerated autolysis and putrefaction, rapid onset of advanced decomposition resulting in mummification, and rapid skeletonization and disarticulation if remains are exposed to terrestrial or avian scavengers. Figures 32 and 33 show the relatively quick amount of time it
took for SS1, SS2, and SSC to reach the advanced stage of decomposition resulting in mummification.

One of the most glaring differences between arid or semi-arid climates and humid climates is how the moisture acts upon the remains. The relatively low mean humidity in western Montana results in the speeding up and slowing down of the entomology on the remains. The humidity is highest in the evening and middle of the night, but drops drastically during the day. As the temperature increased throughout the day, and the humidity decreased, the insect activity appeared to slow down, dramatically.

Figure 32: Datalogger Information for Research Site from researcher for SS1 and SS2
Entomological Results

Entomological specimens collected by the researcher and identified by Dr. Ralph E. Williams, for this study are described below. By far, the most common order of Diptera collected were young adults, adults, and immatures/larvae from the family, Calliphoridae, and the species *Phormia regina* (black blow fly). They are Holarctic in distribution. According to Byrd and Castner (2010) these blow flies are considered to be a cold weather fly, and are most abundant in the spring and fall throughout the United States with the exception of southern Florida. In the northern latitudes of the United States and southern Canada, *P. regina* are often found throughout the summer months. *Phormia regina* are most common in the winter months in the southern United States. The second most common order of Diptera collected were from the family Sarcophagidae. Sarcophagidae are flesh flies and comprise a large family with over 2,000 species which occur in the United States and Canada. Female flies in this family deposit living first-instar larvae instead of laying eggs. According to Byrd and Castner (2010) the family’s
Latin name means “flesh eating” which apparently refers to the maggots feeding on carrion. In addition to the Diptera, many samples of beetles (Order Coleoptera) were also collected and identified. Coleoptera is the largest order, containing about a third of all known insects. The most common Coleoptera collected and identified were from the Families Staphylinidae (rove beetles), Dermestidae (skin beetles), Histeridae (clown beetles), and Silphidae (carrion beetles). They include the *Creophilus maxillosus* (common name: Hairy rove beetle), *Dermestes ater* (DeGeer) (common name: Black larder beetle, incinerator beetle), *Necrobia rufipes* (common name: Red-legged ham beetle, copra beetle), *Thanotophilus lapponicus* (common name: Lapland carrion beetle, northern beetle, common carrion beetle) and clown beetles (Family Histeridae).

Most of the insect scavenging occurred after the adult Diptera deposited their eggs, and continued until most of the tissue was mummified. Many of the Sarcophagidae (flesh flies) and Coleoptera (beetles) fed on the adult Calliphoridae (blow flies) and blow fly larvae as well as on the remains until and after mummification. The blow fly larvae mainly fed on the carrion. The most abundant insect activity was recorded during the morning observation period after the sun had come up at approximate 7:00 AM, as the temperature was rising, and the humidity was still high. The insect activity appeared to drop off during the late afternoon observation period when the temperature was the highest and the humidity was at its lowest, which was normally at 4:00 PM. This was a good indication that temperature was not the most important factor of insect scavenging in western Montana. During the hottest part of the day, the maggots/larvae were sluggish and did not appear to be feeding on the remains at the same feverish pace as they did when the temperatures were lower. In addition, the high ambient temperature coupled with the metabolic temperature of the maggot mass were harmful for the maggots as temperatures often exceeded those in which the maggots could survive; whereas, when the temperature was a bit

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cooler, the metabolic temperature from the maggot mass did not contribute to the death of the maggots as the maggots could survive the cooler maggot mass temperatures. Although the two enclosures had separate micro-environments, there was not much difference in the temperature, as it only deviated by 1-3° C as most. In addition, the insect activity seemed to be very similar in the two enclosures with the exception of the later arrival of insects to Enclosure 2, most likely due to more limited access for the insects. After the first 2-3 days of insect activity, the two specimens appeared to even out in terms of biomass loss and decomposition stages.

For all 3 specimens, nearly all of the insect activity ceased after mummification. This is true for both the sun and the shaded specimens. Some beetle activity remained underneath the specimens to feed on the areas that still exhibited some nutritive value, but not in great numbers. The beetles were most plentiful in Enclosure 2 after mummification. This could be due to the micro-environments, suggesting that beetles prefer to be protected from the sun. It could also be assumed that the beetles remained to feed on the postfeeding and migrating larvae.

Table 8 depicts the collection of entomological evidence collected from SS1 and SS2, from 8/1/2011 to 9/8/2011, during the first part of the research study. Additional entomological samples were taken from SSC, but are not presented on this table. Samples from SS1, SS2, and SSC were collected and recorded. They are shown in Appendix E. Many of the samples did not make it to Dr. Ralph E. Williams, for identification. Some were destroyed in the shipping process, while others were lost due to improper preservation processes.
An unusual result in this study was that the larvae in the shaded enclosure did not grow as large as those in the full sun enclosure. Postfeeding and migrating larvae observed and collected from Enclosure 2 were mostly smaller in size than those observed and collected in Enclosure 1 during the 8/1/2011-8/20/2012 research period. Postfeeding larvae can be smaller depending on the species, but most of the larvae collected were determined to be from the same species. Because Enclosure 2 was shaded and protected, it was hypothesized that without the sun beating down on the larvae, they would have a longer opportunity to feed on the specimens, which would most likely result in larger larvae. The humidity in Enclosure 2 was usually slightly higher than the humidity in Enclosure 1. Both of these factors (shade and higher humidity) would seem to be conducive to longer periods of feeding for the larvae in Enclosure 2, which would lead to larger postfeeding larvae. Further research in this area may lead to an explanation of this phenomenon.
Huntington and Higley (2008) give an example of how to calculate accumulated degree days (ADD) to arrive at PMI. The first step is to determine the base temperature (the temperature where no development is predicted) of the blow fly that is going to be utilized. The second step is to determine the average daily temperature at the death scene. The third step is to subtract the base temperature of the fly from the daily average temperature. The difference in temperature equals the amount of degree days needed for a 24 hour period. For example, 20°C-10°C = 10 degree days. If, for example, the blow fly needs 400 ADD to go from the egg to the pupal stage-400/10 (degree days) = PMI of 40 days. By far, the most common order of Diptera collected were young adults, adults, and immatures/larvae from the family, Calliphoridae, and the species P. regina (black blow flies).

The ambient temperature ranged from 17.5-32.4°C. The mean ADD was 174, with the standard deviation of 3.0. The time to reach this stage at 23°C was 9.6 days. In order to reach 174 +/- 3 days of accumulated degree days in Montana, approximately 8 accumulated degree days were required.

It is my hypothesis that the PMI from the most common species of Diptera in this study will demonstrate the best PMI available among the three methods presented. In the current study, P. regina-which was the most abundant blow fly collected-was collected on all 3 specimens on day 4-5 and the adult emergence was observed and collected on day 14-16. This results in a PMI estimate between 10-12 +/- 3 days. I can accept the hypothesis that the PMI from this method is the most accurate of the 3 tested because the PMI estimate of 8 accumulated degree days falls within the 10-12 +/- 3 accumulated degree day time period tested in this method.
Scavenging Results

Figures 34 and 35 from the Montana’s Official State Website in their Montana Field Guides section (http://fieldguide.mt.gov/detail_ABPAV09010.aspx) Montana Field guides show the general distribution of Black-billed Magpies. According to the website, historically, the Black-billed Magpie often followed Native Americans and lived on the debris of their hunts. During breeding season, they will be found in thickets in riparian locations, usually associated with open meadows, grasslands, or sagebrush for foraging. Frequently, the Black-billed Magpies will be found near human habitats such as livestock feedlots, landfills, barnyards, and grain elevators (Trost, 1999). The food mainly consists of ground-dwelling arthropods, seeds, and carrion (Trost, 1999). According to Trost (1999) the Black-billed Magpie is medium-sized and boldly patterned. Males are larger than females (Trost, 1999).
Figure 34: Black-billed Magpie (*Pica hudsonia*) from Nathan DeBoer
According to Selva and Fortuna (2007) scavenging is a widespread phenomenon which has seldom been accounted for, in spite of playing a crucial role in food webs by reinforcing nutrient recycling and community stability. Scavenging is a type of detrital feeding that should have widespread consequences for the structure and stability of food webs (Wilson and Wolkovich, 2011). According to Wilson and Wolkovich (2011) because of the high quality of carrion,
scavenging is usually fast and widespread; multi-species scavenger guilds dominate the carnivore trophic level in various ecologic systems. Most scavengers (e.g. obligate, facultative) are also predators, which also qualifies them as opportunists. Scavenging using detrital feeding allows access to exceptional food resources without having to hunt down, and kill their prey. This type of detrital feeding conserves energy.

In this current study, the avian scavenging demonstrates how facultative scavengers utilize consumption efficiency to feed on carrion during all 4 seasons. The following photographs will demonstrate how (1) avian scavengers first arrived at the site to feed, most efficiently, on the arthropods, (2) when the arthropods were consumed, initially the English sparrows entered Enclosure 1 to feed on the arthropods remaining on or near the remains, (3) when the Black-billed Magpies ascertained how to enter the enclosure through the very narrow 9 cm x 9 cm openings in the fencing material, they encroached on the English sparrow’s feeding environment, and (4) once the Black-billed Magpies learned how to gain access to the enclosure, they kept returning until scarcely any food source was available (Figures 36-48).

In this study, the Black-billed Magpies began to feed on the specimen associated insects from SS1 on day 12. From the 9th day of the study until 05/19/2012, the Black-billed Magpies appeared almost daily to initially feed on the arthropods, and eventually, on the soft and hard tissue of SS1. With the exception of a short amount of time when the enclosure was tampered with, by someone placing chicken wire over the enclosure to prevent the scavenging, the Black-billed Magpies scavenged on SS1 nearly every day. The only time that the Black-billed Magpies fed on the SS2 cadaver, was after all of the nutritive elements on SS1 were depleted. The Black-billed Magpies were pictured on the time-lapse camera in Enclosure 2 on 4 separate dates. On 2 of those occasions, the Black-billed Magpies appeared agitated and apprehensive and only
remained in the enclosure for a few seconds. They did not feed on the remains during these visitations. They only fed on SS2 during the 2 additional occasions. The reason why the Black-billed Magpies fed on SS1 more than SS2 was due to the protective cloth that was covering Enclosure 2 in order to replicate a naturally shaded/protected micro-environment. Because avian scavengers have such keen senses of sight, it is important for them to feed in areas where they can view both their predators and prey. When they were in Enclosure 2, they were unable to observe their predators; therefore, they did not stay in Enclosure 2 longer than a few seconds per visit.

Figures 43-45 reveal how the Magpies continued to feed on the remains even during heavy snowfalls. On several occasions, they would arrive after a new snowfall, and remove the snow in order to feed off of the remains.

Unlike vultures that do not utilize the skeletal remains, Black-billed Magpies spent much of their time feeding on the hard tissue from SS1. In particular, they fed on the mandibular condyles, ribs, vertebrae, both scapula, both clavicles, and portions of some of the long bones. In addition to feeding on the skeletal remains, the Black-billed Magpies spent much of their time trying to remove the skeletal elements from Enclosure 1. Initially, they would hold the skeletal elements in their beaks, and attempt to escape the enclosure through the narrow openings. Realizing their attempts were futile, the Black-billed Magpies resorted to pushing the skeletal elements out of the enclosure from the inside, and retrieving them once they had exited the enclosure. Many of the skeletal elements were lost due to the Magpies carrying them away. On a few occasions, the Magpies were able to remove the skeletal remains from the enclosure but did not take them with them when they flew back to the safety of their homes. Some of the skeletal elements that were pushed out of the enclosure, but not removed from the area were the
vertebrae. Nearly all of the ribs that were removed from the enclosure were carried away. It could be hypothesized that the Black-billed Magpies may have wanted to utilize the ribs for nest building. On several occasions, the Black-billed Magpies were observed on the time-lapse camera attempting to remove the mandible from Enclosure 1. They were very diligent in their attempt, but did not succeed in removing it from the enclosure. After most of the usable skeletal elements had been scavenged and removed from Enclosure 1, the Black-billed Magpies moved onto SS2 in Enclosure 2.

Due to the apprehension of not being able to view their surroundings, the Black-billed Magpies spent very little time in Enclosure 2. The first time that the Magpies spent longer than just a few seconds in Enclosure 2 was in late May. From May through the end of July, the Black-billed Magpies slowly began to scavenge SS2. The main goal was to feed on the soft tissue that had been mummified since early August of 2011. Very little time was spent feeding on the skeletal elements. None of the skeletal elements were removed from Enclosure 2.

Figure 36: Enclosure opening: 9 cm x 9 cm
Figure 37: Black-billed Magpie squeezing through fence

Figure 37 is a copy of a time-lapse photograph in which a Black-billed Magpie was able to squeeze through the 9cm x 9cm opening of Enclosure 1. This is the method they used to gain entrance to the cadaver. At no time did the researcher witness a Black-billed Magpie in any enclosure. All photographs that depict this evidence were produced by the time-lapse cameras. In addition, when the time-lapse photographs were viewed, the Magpies were observed to leave Enclosure 1 when I arrived on scene but returned within seconds after I left the site. At times, the Magpies fed alone, but more often than not-after 1 Magpie entered Enclosure 1 to feed-others would join in. This was not the case for Enclosure 2. At the most, 2 Magpies were observed to be feeding on SS2 in Enclosure 2, whereas with SS1 there might be 1-20 Magpies feeding at any given time in Enclosure 1.
Initially, only the English sparrows were able to enter the enclosures. They were observed to be feeding on insect larvae. The Black-billed Magpies also fed on the larvae, but remained outside of the enclosures until they ascertained how to gain entry into the enclosures. Once the Magpies gained entry, the English sparrows no longer entered the enclosures. This could be a good example of how the avian scavenging guild operates, with the Magpies being the dominate scavenger over the English sparrows.
Figure 39: Day 7 Black-billed Magpies feeding on arthropods outside of SS1 Enclosure

Figure 40: Day 47 Magpies feeding on SS1 Cadaver
Figure 41: Day 55 Magpie feeding inside and outside enclosure

Figure 42: Day 86 Magpie Feeding
Figure 43: Day 169 Magpies feeding in winter

Figure 44: Day 183 Magpies Feeding in winter
Figure 45: Day 224 Magpies feeding through the snow

Figure 46: Day 253 Magpies skeletonizing SS1
As evidenced from Figures 47 and 48, very little of SS2 was scavenged as the Magpies chose to replete all resources from SS1 before scavenging on SS2. As mentioned before, without the ability to observe their surroundings, it is my belief that the Magpies did not feel safe scavenging in an area where they could not have a view of potential predators. On day 291 (5/16/2012) of the study, more of the specimen had been scavenged to a point in which a TBS of 24 was recorded. The TBS score lasted until day 353 (7/17/2012) when the score needed to be increased to a 26 for the duration of the study. The increase of TBS was caused by scavenging from Black-billed Magpies. In Figure 47, approximately 25% of the remains had been scavenged. By the last day of the study, in Figure 48, approximately 45-50% of the soft tissue had been scavenged from the remains. Both of these decomposition scores are subjective interpretations, as other researchers may believe that more or less of the remains have been scavenged. This is where Vass (2011) comes into question. How does one realistically come up with precise estimation of percentage of decomposition that all researchers could agree on?

The bones of SS2 still appeared to be greasy, and wet. No bleaching of the bones was present, most likely due to the 90% UV protection by the shaded enclosure. It is possible, that if the remains had been left at the research site for longer than a year, more of the soft tissue and possibly the skeletal elements may have been scavenged.
Figure 46: Day 291 of SS2 displaying very little scavenging

Figure 47: Day 365 of SS2: last photos of scavenged remains
Several hypotheses were posited for this thesis. The first hypothesis is predicated on the supposition that cadavers that are placed outdoors in the hot, semi-arid environment of western Montana, in August will mummify rather than advance to the skeletonization stage without the aid of scavengers (Parsons, 2009; McKeown et al. 2011). I can accept this hypothesis. The second hypothesis is predicated on the supposition that the accumulated degree day (ADD) formula developed by Megyesi et al. (2005) to estimate the time since death (TSD) or postmortem interval (PMI) using the total body scores (TBS) will not work in Montana as most cadavers will either reach stasis in the form of mummification in a short period of time (8-15 days) in the summer, or become scavenged; this is based on previous research by Parsons (2009) and Dudzik (2009). I can accept this hypothesis. The third hypothesis is predicated on the supposition that the most accurate PMI estimate will come from the entomological evidence; specifically on the life cycle of the *P. regina* blow fly, which is the most abundant blow fly identified in this study. I can accept this hypothesis. The final hypothesis is predicated on the supposition that the specimen that is placed in the full shade enclosure will decompose more slowly than the specimen placed in the full sun enclosure. I will reject this hypothesis, even though SS1 proceeded through the decomposition at a slightly faster rate than SS2. Both SS1 and SS2 eventually caught up with each other. The only factor that influenced the decomposition rate of SS1 and SS2 after mummification was the event of scavenging which has nothing to do with the micro-environments of sun versus shade.
Chapter 5: DISCUSSION

The purpose of this study was to document the process of decomposition for 3 pig (*Sus scrofa*) cadavers in Montana deposited on the ground surface in two different micro-environments (full sun versus full shade) with one exposed to avian scavenging. A secondary purpose for this study was to ascertain why the pattern and rate of soft tissue decomposition in previous studies in other geographic areas throughout the country appear to be so different from the previous studies conducted in Montana. In attempting to understand these inconsistencies, methods for estimating PMI or TSD were tested in this study. As you will see, 2 of the 3 methods to estimate PMI were found to be problematic in this study, while the 3rd method appeared to work much better; although it, too, had its drawbacks.

Furthermore, most previous studies, including Megyesi et al. (2005) and Vass (2011), have not considered the event of scavenging, and what affect it would have on the decomposition process. In the current research, avian scavenging was allowed to reveal how they can affect loss of soft tissue as well as the estimation of ADD, and ultimately cause the researcher to miscalculate the PMI using the Megyesi et al. (2005) system. The aerobic formula for PMI from Vass (2011) was also tested in the current study to show how a researcher’s conceptualization of percentage of decomposition can also adversely influence the PMI estimate from Vass (2011). Errors in the formulas as well as interobserver errors can have negative consequences when PMI estimates for forensic cases are shared with medico-legal personnel, in order to determine time since death for the decedent. The estimates are often under and over the actual PMI which calls into question whether or not these formulas are appropriate for precise estimations in real forensic cases. This study reveals that the PMI estimates can be off by days, weeks, months, or even years. Both methods (Megyesi et al. 2005; Vass 2011) lack precision, alternative variables,
and accuracy. The final method examined to estimate the PMI is predicated on the concept that when correlated with environmental temperatures, development of forensically relevant blow flies can provide an accurate PMI using the formula found in Nabity et al. (2006). The PMI estimate from the blow fly life cycle is generally most useful only in the first 2 weeks to 20 days of TSD, but it is the most useful of the 3 methods in Montana.

**Stages of Decomposition**

The first objective of this study was to conduct longitudinal, empirical examinations of all cadavers at the research site in order to establish patterns and rates of decomposition in this bioclimatic region. The initial stages of decomposition in this study were consistent with most decomposition studies conducted in the summer in Montana and other sites throughout the country, with high Diptera and Coleoptera activity, accelerated autolysis, putrefaction, and rapid rates of decomposition with moderate temperatures and low temperature. In contrast, decomposition rates in areas with high humidity and high temperatures during the summer can be markedly different. For example, “the Forensic Anthropology Research Facility (FARF) at Texas State University-San Marcos is located in an area subject to various weather conditions characteristic of a sub-tropical climate, in which the humid climate may be punctuated by periods of drought leading to semi-arid conditions” (Suckling, 2011, p. 2).

The fresh stage in this study compared to other studies in Montana by Parsons (2009) and Dudzik (2009, and Galloway (1989) in southern Arizona reveal that there can be a wide variation depending on spatial and temporal context. In Parsons (2009) the fresh stage on SS-1 began on day 1 and continued until day 2 when the carcass began to bloat. Specimen SS-1 was placed on the surface on 8/6/2008. Specimen SS-2, which Parsons (2009) shared with Dudzik (2009) experienced the fresh stage for 55 days. The specimen was placed on the ground surface on
10/13/2008. Dudzik (2009) placed an additional specimen-SS-3-was placed on the ground surface on 11/20/2008. The fresh stage was not observed; instead Dudzik noted that there were no observed changes to SS-3 during the first week. Additionally, she notes that SS-3 remained in the early stage of decomposition for 53 days, from day 146 to day 199. In Galloway (1989) out of 189 cases examined, 23% were classified as fresh. The fresh stage lasted from 1 day to 8 days. All cadavers in the current study were placed at the research facility within 3-4 hours following death. When the cadavers were received, bloat was already observable and increasing rapidly, lividity was fixed, and rigor was underway; therefore, the fresh stage and bloat stage overlapped for this study. Both SS1 and SS2 experienced the greatest amount of bloat on the second day, and began to deflate on the third day. Cadaver SSC experienced the greatest amount of bloat on the 3rd day, and began to deflate on the 4th day. Ambient temperature for the first 3 days of the research study, for SS1 and SS2, averaged 23.5°C, while the ambient temperature for the first three days for SSC averaged 22 °C. SS1 and SS2 were placed on 8/1/2011 while SSC was placed on 8/1/2012.

Almost immediately, it was obvious that the categories and stages of decomposition from the Megyesi et al. (2005) study were not congruent with the qualitative observations in the current study. During initial placement of all specimens, which occurred between 5:00 PM-5:30 PM, bloat was observed on what would normally be considered the fresh stage of decomposition. When the specimens were observed in the morning of the 2nd, 14 hours after initial deposition, decomposition purge was exuding from the nose, mouth, and anus. Due to the decomposition purge, a score of 5 for the head and neck; a score of 4 for the trunk, and a score between 1-3 for the limbs was recorded which resulted in a TBS of 11 on SSC, a score of five for the head and neck, a score of 4 for the trunk, and a score of 3 for the limbs was recorded which resulted in a
TBS of 12 on SS2, and a score of 5 for the head and neck, a score of 4 for the trunk, and a score of 3 for the limbs was recorded which resulted in a TBS of 12 for SS1. These differences seem to indicate that the fresh stage and bloat stage of decomposition overlapped for SSC, SS1, and SS2, respectively, concluding that the decomposition observed in the current research did not appear to parallel the sequence definitions from Megyesi et al. (2005). This statement by Megyesi et al. (2005) “Deviations from the decomposition sequence are rare and the decomposition observed in photographs matched the progression of decomposition outlined in this scoring strategy very well” (p. 4) is unsubstantiated in the current study. Additionally, although there was discoloration of the flesh on all specimens, discoloration did not progress according to the categories listed in the Megyesi et al. (2005) study.

In the semi-arid climate of Montana, it would seem appropriate to reintroduce the advanced decomposition point system from Galloway et al. (1989) back into the Megyesi et al. (2005) scoring system. These categories could include: 1) an (8 pt) score for mummification, with some retention of internal structures, and 2) a (9 pt) score for mummification of outer tissues only, with internal organs lost through autolysis or insect activity. Megyesi et al. (2005) reveals that mummification does not occur quickly in temperate climates, so the stages reflect the progress as it transpires in non-desert regions of the United States (p. 2). This statement suggests that mummification occurs only in desert regions, which is inaccurate. The only time that the skeletonization stage was observed in the current study was after SS1 and SS2 had been scavenged by Black-billed Magpies. Likewise, it may be appropriate to add a decomposition category or scoring system to the Megyesi et al. (2005) method which would include the event of scavenging. One problem with this suggestion is that scavenging can occur at any point and time during the decomposition process, so try to determine how to score it would be problematic. The
skeletonization stage would not have come to be without the scavenging activity. These inconsistencies created a quandary when attempting to arrive at a total body score (TBS) during each site visit. Often, the scores had to be recorded as 2 separate scores because none were applicable. Once the mummification stage was reached, which was on day 7 for SS1, day 9-10 for SS2, and day 9-10 for SSC, respectively, the condition of the cadavers remained essentially unchanged through the duration of the study. If the categories of “mummification” and “scavenged” were incorporated into the Megyesi et al. (2005) study, the system might be more explicable.

Something that has not been mentioned, but needs to be addressed is the fact that Montana has 4 totally different seasons. During the current study, all cadavers were placed in August, which made the TBS easier to quantify. If a cadaver was placed in the winter or early spring in Montana or in other cold climates, the utility of TBS and ADD to estimate PMI could be inapplicable due to stasis during colder periods, as indicated in Parsons (2009) and Dudzik (2009). According to Megyesi et al. (2005) any days that are at or below freezing should be recorded as 0 for the ADD, as negative values are not favorable for the mathematical equation. During this study, in the winter and early spring, over 80 days were not included in the ADD calculations as those days resulted in a mean temperature of freezing or below freezing (0 °C or lower).

TBS plotted against ADD as depicted previously in Figure (30) shows how quickly all specimens advanced through the decomposition stages. The semi-arid climate with deposition occurring in August was a huge factor in the rapid decomposition. Also apparent is the prolonged advanced decomposition stage. This was due, in part to the early mummification and also due to stasis during the colder temperatures in the fall and winter months. On SS1, the increase in the
TBS only occurred once the Black-billed Magpies had scavenged enough of the remains to record a higher TBS. Even though the Black-billed Magpies began to scavenge SS1 after only 12 days, they did not remove enough soft tissue to score a 10 or higher in the Megyesi et al. (2005) scoring system on the head and trunk until 8/6/2011 and on the limbs until 1/1/2012. Between 8/9/2011 and 10/10/2012 the TBS for SS1 remained at 28.5. After 10/10/2012 the Black-billed Magpies scavenged the remains more thoroughly resulting in a final TBS on 8/1/201 of 33. On SS2, the head, trunk, and limbs TBS remained the same: 7-9, 8, 7, respectively, from 8/7/2011 until 1/1/2012 with a TBS of 23. The TBS on SS2 scored a slightly higher point score of 23.5, due to the bone exposure on the head only. The trunk of SS2 continued to show a point score of 8 until 6/21/2012. The limbs of SS1 scored a 7 from 8/7/2011 until the end of the study. SS2 only scored a 10 on the trunk after 6/21/2012, resulting in a TBS score of 26, due to the Black-billed Magpie scavenging. SSC was quickly advanced from a TBS of 3 on day 1 to 19.5 in just 15 days, at which time the remains were mummified, not accessible to scavengers, and adequate data was collected to show that without scavenging-SSC would not advance to a higher TBS score for many more months. The study concluded on 8/20/2012. The TBSs were recorded as 33 for SS1, 26 for SS2, and 19.5 for SSC.

Megyesi et al. (2005) utilized photographs for their study. It is my opinion that using only photographs to score the stages of decomposition in order to estimate PMI is inappropriate and could be misleading when presenting the results to medico-legal personnel. In Megyesi et al. (2005) much of the information utilized for TBS consists of color changes. It is common knowledge that digital photographs can produce completely different results depending upon whether or not a flash was used. In addition, the color and hue on digital photographs can be altered, which could change the determination of the point system given for Megyesi et al.
(2005), thus biasing the sample. Another obvious problem with utilizing only photographs to develop the data set is that there is no consistency in how the photographs are taken. A blurry photograph will not yield the same information as a clear one, but neither option is ideal. There is no adequate substitute for empirical observations. Empirical observations allow the researcher to record the specimens in situ, record odor changes, touch the specimens, and document activity as it occurs rather than retrospectively collecting data off of photographic evidence. I do not believe that the use of photographs should be completely excluded as it is the only option for many forensic cases, and we have to make do with what we have. The best case scenario in a forensic case would consist of the forensic anthropologist attending the crime scene in order to observe the scene, first hand.

The Vass (2011) PMI equation tested in this study revealed that trying to estimate a percentage of decomposition was too subjective. One observer may estimate a rate of 40% decomposition on a cadaver while another observer may estimate a rate of 80% decomposition on the same cadaver. This clearly presents a problem in that the PMI estimate using the Vass (2011) method could be thrown off by days to weeks due to different observer’s estimates of decomposition percentage. The two examples presented in this study demonstrate how one observer might determine a higher percentage of decomposition on a cadaver than another observer. But both examples displayed a PMI from the Vass (2011) method as being quite inadequate. This may mean that the equation needs to be re-worked to provide for mummification and scavenging. According to Vass (2011) this equation is meant to provide a fast but rough estimate of PMI when medico-legal personnel are limited in time. Clearly, if medico-legal personnel were given a PMI of 30-60 days when the actual PMI was 6 days, and if they were given a PMI of 71-88 days when the actual PMI was 9 days, this would present a
problem. Currently, there is too much ambiguity in these two methods (Megyesi et al., 2005, Vass, 2011) for this researcher to recommend either of them to medico-legal authorities in a forensic case.

Another important element of this study was the use of two different micro-environments (full sun versus full shade). Sharanowski et al. (2008) found that the sun-exposed carrion has greater variation in fauna than the shaded carrion in spring and fall (abstract). Shean et al. (1993) found that the exposed carrion decomposed faster than the shaded carrion. Although the two micro-climates were very different as far as exposure to the sun, wind, and other climatological conditions the specimens within the 2 enclosures decomposed at relatively similar rates. Within the first week of decomposition, the full sun exposed pig was decomposing at a slightly faster rate than the full shade pig. It appeared that the insect activity on SS1, from Enclosure 1, was a full 24 hours ahead of the insect activity on SS2, from Enclosure 2. The control pig, SSC, more closely mimicked the decomposition process of SS1. The insect activity could have been the result of the insects being able to see and smell the decomposing remains more easily in Enclosure 1 than Enclosure 2. Both were contained within Enclosure 1, which was fully exposed to the sun and other elements. After the first week of decomposition, SS1 and SS2 began to decompose at a more consistent rate. From the third week onward, the decomposition stages were almost identical until the Black-billed Magpies began scavenging SS1, thus changing the appearance and TBS of the full sun pig. The full sun enclosure also received much more snow than the full shade enclosure. Amazingly, this made little difference to the decomposition process as the mummified specimens were unable to absorb the moisture from the snow. The appearance of the specimens changed for a short amount of time with the addition of moisture, but not considerably. The color often changed from a lighter color to a darker color, but reverted
back within hours or sometimes if the moisture continued, the color would remain the same until
the added moisture ceased. Of interest, the mummified skin remained hard and did not become
pliable with added moisture.

Lastly, this study will discuss the decomposition process of the separate Montana research
projects. The previous decomposition studies conducted at Lubrecht Experimental Forest,
approximately 53.10km from the current study are a bit different which was to be expected.
Parsons (2009) study utilizing an August pig most closely resembled the current research project.
For the most part, Parsons’ (2009) findings are similar to the current research. However, with the
exception of detailing the entomological activity, little data exists of the decomposition process
after day 15. In the results chapter of Parsons (2009) she notes that on day 7 the advanced
decomposition stage began, and the carcass continued to dry out. Additionally, in the
accumulated degree day section of Parsons (2009) study she noted that the limbs had reached an
advanced stage of decomposition which resulted in a score of 7 of the Megyesi et al. (2005)
system. The next TBS recorded for Parsons (2009) study was on 9/9/08 which was day 36 of the
study. At that time, the TBS was recorded as 23 for her August specimen. On day 65, the TBS
was recorded as 24. On day 83, the TBS was recorded as 24. Finally, on day 250 of ADD
observation a TBS, the TBS was recorded as 24. This is indicative of little to change to the
specimen for over 185 days, and little change from day 36 to day 65. Parsons (2009) revealed
that the ADD method generated PMI estimates two weeks before the actual time since death for
the two cadavers in her study during the earlier stages of decomposition. In addition, Parsons
(2009) revealed that as the decomposition progressed, the ADD model from Megyesi et al.
(2005) to estimate PMI became more accurate. It is her estimation that when decomposition
slows and degrees accumulate, the accuracy of the ADD model is demonstrated. Parsons (2009)
reveals that the accuracy of the ADD method from Megyesi et al. (2005) works better in the later stages of decomposition, and is less accurate during the earlier stages of decomposition. The current study does not support Parsons (2009) results.

The rates of decomposition for Parsons’ (2009) August pig closely resemble the rates of decomposition for the current study. The only real difference in structure of the 2 studies is the accessibility of scavengers to SS1 and SS2 in the current study. Due to the event of scavenging in the current study, TBS increased slowly over the course of the one year study. The largest amount of scavenging took place on SS1 in the current study which resulted in a TBS of 33. The Parsons (2009) study and the current study differ in the elevation and environmental details. The results from both studies prove that although studies in Montana can vary from each other, they are most closely related to each other than those in different geobioclimatic zones. In order to study the decomposition process, the researcher needs to study the area where the decedent is located.

**Entomological Analysis**

The current study reveals that the rapid onset of mummification played a significant role in the decomposition process. For example, in climates that are more humid where mummification does not take place, insects can play a bigger role in biomass loss from the remains. On the other hand, in this study, the low humidity and hot temperatures desiccated all remains which rendered the specimens not as attractive to the insects. An adult fly will normally not lay her eggs on non-nutritive tissue, so the original wave of succession could be the only wave of succession from insects on mummified remains. Coleoptera will still colonize the remains, but much of the biomass is consumed by the Diptera larvae. Mummification makes estimates of PMI difficult, if
not impossible. It is questionable whether a practitioner should provide a PMI estimate when mummification is present.

The most common and abundant Diptera collected and identified in this study were the *Phormia regina* (black blow fly). Both adult and immature *P. regina* were collected. Because *P. regina* is well studied in the literature, is utilized as a primary species to estimate PMI, and is regularly associated with death scenes, investigation of the temperature-developmental time is necessary (Nabity et al., 2006). *P. regina* is an important blow fly common in western Montana. Immature *P. regina* in the 1st through 3rd instar were collected from SS1, SS2, and SSC between the sixth and 15th day of the current study. Adult *P. regina* were collected after the emergence on 8/16/2011 along with a few Sarcophagidae (flesh flies) Nabity et al. (2006) reveals that in order to use larval development to estimate PMI, accurate information on the development of individual species is crucial. The information that is currently available comes from just a few studies (Kamal, 1958; Byrd and Allen, 2001; Higley and Haskell, 2001; Huntington and Higley, 2008). It is important to use the fastest developmental time (generally based on higher temperatures) of the blow fly when calculating the PMI, as most environmental factors (colder temperatures, rain, wind) slow down rather than speed up the development period (Nabity et al., 2006, p. 1277). The results from the Nabity et al. (2006) study reveal the development time from oviposition to adult emergence of the *P. regina*. At a temperature range of 17.5-32.4⁰C, the accumulated degree days showed a mean of 281 with a standard deviation of 3.6. The average time to reach the adult emergence stage at 23⁰C is 16.1 days. The accumulated degree day figures for Montana in August of 2011 revealed that the accumulated degree days of 281 +/-3.6 fell between August 13th and 14th, which is a slightly shorter development time than the development time in the Nabity et al. (2006) study. The PMI estimates from this method are the
closest methods encountered in the current study; however, the method is limited to the ability for death investigators or forensic entomologists to collect larvae. Larvae only remain on a viable food source until they have reached the postfeeding stage at which time they migrate away from the food source in order to pupate. Diptera development can be highly variable depending upon climates and other variables. In insects, the circadian system is responsible for imposing daily rhythmicity on a wide variety of processes including locomotor activity, mating, ovi- or larvaposition, egg hatching, pupation and pupal eclosion, pheromone release, retinal sensitivity to light, olfactory sensitivity, and even learning and memory (Saunders, 1982). Consequently, some factors in the circadian system speed up development while other factors retard development. Nabity et al. (2006) estimated the *P. regina* development time from oviposition to pupation. The temperature ranged from 17.5-32.4°C. The mean ADD was 174, with the standard deviation of 3.0. The time to reach this stage at 23°C was 9.6 days. In order to reach 174 +/- 3 days of accumulated degree days, in Montana, approximately 8 ADD were required. A table from Kamal (1958) estimates that the *P. regina* development time from eggs to pupa with a constant rearing temperature of 26.7°C would take 215.0 accumulated degree days. 215 ADD would have taken place on 8/10/2011, which was approximately 9 days after deposition of the cadavers.

Barnes (2000) found similar Diptera (flies) and Coleoptera (beetles) in his study at Lubrecht Experimental forest. His study was an entomology study, so he spent much more time collecting specimens. Barnes (2000) also found more species of Diptera (flies), Coleoptera (beetles), and other orders. Many of his species were unidentified. Additionally, he collected more species in the post-decay and remains stage than was collected in the current study. The inconsistency could be due to the environments and vegetation. A thickly forested area may attract more
insects than a dry, hay field. Along with many of the same species in the current study, Barnes (2000) also collected Hymenoptera (fire ants), Acari (mites or ticks), Lepidoptera (butterflies and moths), Hemiptera (stink bugs), and Araneidae (spiders). In addition, although both studies collected many of the same species of Diptera and Coleoptera, Barnes (2000) collected more species than the current study. Many of the Barnes (2000) species were not collected or remain unidentified. Most of the species collected by Barnes (2000) were adults. The only immature species in the Barnes (2000) study were the *Phormia regina* (black blow fly), *Thanatopilus lapponicus* (Lapland carrion beetle), *Dermestes* (skin beetle), *Lucilia illustris* (Meigen blow fly), *Necrodes surinamensis* (Surinam carrion beetle), *Sarcophaga* (unidentified flesh fly), *Prochyliza brericornis* (Diptera: Piophilidae), and *Prochyliza xanthostoma* (Diptera: Piophilidae).

**Effects of Scavenging on Decomposition**

During this research study, it was impossible to prevent avian and small rodent scavenging without making alterations to the enclosures. As this was a longitudinal study looking for the variables that effect decomposition, scavenging was allowed to take place on SS1 and SS2, but prevented from accessing SSC, which was used as the control cadaver. The considerable influence of avian scavenging on the decomposition process in this research study demonstrates that future studies need to consider what scavenging species are in the environment, both spatially and temporally, and where a human body may be found. Insect scavenging activity is not the only scavenging variable in decomposition to consider, avian and terrestrial scavenging also accelerates decomposition to such an extent that PMI can be thrown off by days, months, or even years. For the most accurate estimations of PMI or TSD, all naturally occurring variables such as scavenging need to be included in decomposition studies. Based on 12 retrospective cases with established PMIs analyzed by the Missoula, Montana medical examiners and forensic
anthropologists from the University of Montana over a period of 6 years, McKeown et al. (2011) reveal that many cases of partially and completely skeletonized remains are the result of large carnivore scavenging as opposed to being exposed to the outdoors for an extended amount of time, as previously assumed. McKeown et al. (2011) revealed that remains that retain the external layer of mummified tissue may have not been scavenged. Therefore, when estimating the PMI for all Montana cases, it is crucial to understand the unique patterns of decomposition for the climate, but also the degree of scavenging by large carnivores as this may be a likely factor responsible for the absence of soft and hard tissue. The current study reveals that large carnivore scavenging is clearly not the only type of scavenging that can remove large amounts of soft and hard tissue from remains. Additionally, as evidenced from the material presented in this study, although the Black-billed Magpies scavenged the remains, they did so over an extended period of time. After one year of empirical research, only a small amount of soft tissue remained on SS1 while a great deal of soft tissue remained on SS2. The results suggest that the Black-billed Magpies are facultative scavengers that find a food source, and exploit it over a series of visits. During each visit by the Black-billed Magpies, they scavenged the remains but only remained with the specimens for a few seconds to a couple of minutes at the most. This suggests that unlike the avian scavenging by vultures in central Texas where remains were completely skeletonized in 3 to 27 hours of feeding in Reeves (2009) and 5 hours in Spradley et al. (2011), Black-billed Magpies do not appear to scavenge remains with the same frenetic pace of vultures. This could be a matter of opportunity to scavenge more abundant, alternative food sources while mitigating risk. The size of the carrion as well as the size of the scavenger should also be taken into account. It can be argued and assumed that almost all remains that are discovered outdoors in an unprotected area can be subjected to scavenging, from terrestrial or avian scavengers. This
scavenging event would have a significant impact on any PMI estimate examined in this study. Extreme caution should be exercised when offering a PMI to medico-legal personnel when scavenging has occurred.

The following 4 photographs show the effects of scavenging on SS1 and SS2. The photographs were taken on the last day of the study for SS1 and SS2 (Figures 49-52). It is obvious that the skeletal remains from SS1 are dried out, and gnawed on. The skeletal remains from SS2 still retain some grease and connective tissues.

Figure 49: SS1 on the last day of the study
Figure 50: SS2 on the last day of the study

Figure 51: SS1 scavenged remains
Figures 51 and 52 depict the skeletal elements that remained from SS1. As you can see, there has been extensive scavenging on the remains. The yellow arrow on the left side of Figure 52 show scavenging on the mandibular condyle. Both condyles had been gnawed on. The gnaw marks did not seem to be caused by rodents, as there were no distinguishing rodent marks. No rodents were observed on the time-lapse cameras scavenging on the remains. This does not, however, imply that they did not scavenge on the remains. The gnaw marks appear to be caused from scavenging from avian scavengers, rather than terrestrial scavengers. Additionally, the second yellow arrow on the right side of Figure 51 show scavenging on the scapula. Many of the skeletal remains had been removed by the Black-billed Magpies. Finally, in both Figure 51 and 52, there is evidence of desiccated bone. The bones in Figure 50 are from SS2, and show more greasy bones.
Chapter 6: CONCLUSION

One of the most important factors in a death investigation is the attempt to establish the time since death (TSD) or postmortem interval (PMI) of the decedent. Medico-legal personnel often contact forensic anthropologists to assist them in estimating the PMI. Currently, there are several methods utilized to estimate PMI. The methods and prediction equations examined in this study come from Kamal (1958), Megyesi et al. (2005), Nabity et al. (2006), Huntington and Higley (2008), and Vass (2011). Before a PMI can be estimated, the process of decomposition in the bioclimatic zone where the body has been discovered needs to be fully studied.

The purpose of this study was to conduct research on the unique process of decomposition in the semi-arid climate of western Montana from 8/1/2011 through 8/20/2012 in two separate micro-climates (sun versus shade). All 3 specimens progressed expeditiously through the first 3 stages of decomposition. Within minutes of deposition of the specimens in the research enclosures, blow flies and flesh flies arrived on site. Oviposition and larviposition quickly followed. The succession of arthropods continued as expected, helping to remove a great deal of biomass from the specimens. Additionally, in the current study, it appeared that blow flies and their larvae are much more active in the daylight than in the evening. This evidence supports the theory of the functional importance of the circadian system.

After approximately 7-10 days, each specimen had reached the advanced stage of decomposition. Nearly all larvae had migrated away from the specimens. Only small amounts of postfeeding larvae and various species of Coleoptera remained on and around the specimens. All three specimens had desiccated to the point of mummification. After the specimens had mummified, the waves of succession for blow flies ceased. This was not unexpected as blow flies will not deposit their eggs on tissues that have no nutritional value. Therefore, the only
remaining insects were from the families of Histeridae (clown beetles), Dermestidae (skin beetles), Cleridae (red-legged ham beetles), Silphidae (carrion beetles), and Staphylinidae (rove beetles) from the order, Coleoptera, who stayed to feed on the migrating or postfeeding blow fly larvae and Coleoptera larvae. It must be said that the ambient temperatures at the site averaged $32^\circ C$ during the hot, dry days and dropped down to an average of $11^\circ C$ in the more temperate, but markedly humid evening hours. Most decomposition studies assert that the most important factor in decomposition is temperature. However, this study supports the theory that although temperature is one of the most important factors in decomposition, humidity is also a substantial factor. The mummification could not have taken place without the low daily humidity.

Mummification also occurs in Montana during colder temperatures. The decomposition process is much different in western Montana than other areas that also study the decomposition process.

This study was important as it was the only study conducted, thus far, in western Montana on avian, specifically, Black-billed Magpie scavenging. Although there are several studies on terrestrial scavenging of cadavers, not one exists on Black-billed Magpie scavenging. Several theories have been posited on scavenging, but the results of this study prove why Black-billed Magpie scavenging is an essential factor in the decomposition process in Montana. It can no longer be assumed that if a body is found lacking soft tissue due to scavenging the offender was a terrestrial scavenger, unless there is evidence on the skeletal remains consistent with carnivore activity. Without avian or terrestrial scavenging, the mummified cadavers from this research project would potentially remain undisturbed for years to decades. What was originally an unforeseen oversight, with the Black-billed Magpies squeezing through the tiny 9 cm x 9 cm enclosure openings, turned out to be a blessing as this study would not have been complete without the added scavenging events. The difficulty of keeping the Black-billed Magpies out of
the enclosure begs the question how appropriate it is for taphonomic and decomposition processes to control for scavengers. Instead of controlling for scavengers, we need to understand how to incorporate scavenging into our research of decomposition processes, as they are significant consumers of soft and hard tissues from remains. Depending on the environment, naturally occurring variables such as scavenging need to be included in decomposition studies (Suckling, 2011). In order to go from mummification to skeletonization in western Montana, over the course of a year, scavenging may have to occur.

Four hypotheses were posited for this thesis: I can accept my first hypothesis that cadavers that are placed outdoors in the hot, semi-arid environment of western Montana, in August, will mummify rather than advance to the skeletonization stage without the aid of scavengers (Parsons, 2009; McKeown et al., 2011). I can accept my second hypothesis that the PMI estimate from Megyesi et al. (2005) will not work in Montana as all 3 specimens reached stasis in the form of mummification in a short period of time, and 2 of the specimens were scavenged which does not work with the Megyesi et al. (2005) method. I can accept my third hypothesis that the PMI method for Vass (2011) does not work. I can accept my fourth hypothesis that the most accurate PMI estimate will come from the entomological evidence of the blow fly life cycle. I have to reject my final hypothesis that the specimen that is placed in the full shade enclosure will decompose more slowly than the specimen placed in the full sun enclosure. Even though SS1 proceeded through the decomposition at a slightly faster rate than SS2, both SS1 and SS2 eventually caught up with each other. The only factor that influenced the decomposition rate of SS1 and SS2 after mummification was the event of scavenging which has nothing to do with the micro-environments of sun versus shade.
In closing, the only way to accurately estimate a PMI is to incorporate all variables that effect decomposition. Perhaps the methods developed by the previous researchers need to be reevaluated for other climates. What distinguishes the scientific method from other methods of acquiring knowledge is that scientists seek to let reality speak for itself, supporting a theory when a theory's predictions are confirmed and challenging a theory when its predictions prove false. It is our responsibility as scientists to continually look for better answers, to throw out outdated methods, and open our minds to new methods. It is my opinion that data sets need to be developed in all climates in order to come to have a more complete picture of the decomposition process. Further research needs to focus on disparate climates, and allowances need to be made for the events of scavenging if we are to provide PMI estimates to medico-legal personnel, with any amount of certainty.
REFERENCES CITED


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REQUESTED BY: Teresa ‘‘Lilly’’ White

University of Montana Forensic Anthropology Graduate Student

REQUEST: Soil examination

ITEMS RECEIVED:
One sealed USPS Priority Mail envelope containing two plastic bags labeled individually as:
“Soil sample from SS1/SSC- only 25’ apart from SS2, dated 8/1/11”
“Soil sample from SS2- only 25’ apart from SS1/SSC, dated 8/1/11”

LABORATORY PROCEDURES:
The samples were weighed using an HL-400 balance. Sample SS1 was wet sieved through a series of progressively smaller screens and examined using stereo-binocular microscopy and polarized light microscopy (PLM). Sample SS2 appeared similar in color and texture to sample SS1 and was not examined in detail.
The website, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx, was used to locate and define soil map units in Teresa Whites pig decomposition experiments.

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LOCATION MAPS OF SOIL SAMPLE.
Note: The yellow outlined areas with the numbers are mapped soil units that correspond with map unit descriptions. The soil samples are within unit symbol 46. You are free to use these maps as long as the citation is included. I will let you insert the exact location on the map if you would like.

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This map is the same as previous, just an enlarged scale showing map unit 46 in more detail.

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Soil samples SS1/SS2 are known as the Grassvalley silty-clay loam.

Map Unit Description
Missoula County Area, Montana

46—Grassvalley silty clay loam, 4 to 8 percent slopes

Map Unit Setting
- **Elevation:** 2,500 to 4,500 feet
- **Mean annual precipitation:** 10 to 18 inches
- **Mean annual air temperature:** 39 to 45 degrees F
- **Frost-free period:** 105 to 130 days

Grassvalley soils are used for irrigated and dry land crops and as pastureland and rangeland. The potential native vegetation is blue bunch wheatgrass, rough fescue, needle and thread, and prairie june grass. Soils are well drained; slow to rapid runoff; very slow permeability. Grass valley soils are of small extent in valleys of western Montana.

Description of Grassvalley

Setting
- **Landform:** Lake plains
- **Down-slope shape:** Linear
- **Across-slope shape:** Linear
- **Parent material:** Glaciolacustrine deposits

Properties and qualities
- **Slope:** 4 to 8 percent
- **Depth to restrictive feature:** More than 80 inches
- **Drainage class:** Well drained
- **Depth to water table:** More than 80 inches
- **Frequency of flooding:** None
- **Frequency of ponding:** None
- **Calcium carbonate, maximum content:** 15 percent
- **Maximum salinity:** Nonsaline (0.0 to 2.0 mmhos/cm)

Typical profile
- **0 to 9 inches:** Silty clay loam
- **9 to 21 inches:** Clay
- **21 to 28 inches:** Clay
- **28 to 60 inches:** Clay

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Detailed Soil Map Units

Map units delineated on detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes.

An identifying symbol (your map unit symbol is 46) precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a soil series. All the soils of a series have major horizons that are similar in composition, thickness, and arrangement. Soils of a given series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use.

MICROSCOPICAL EXAMINATIONS:

Sample SS1 (49.4 grams) was wet sieved revealing predominately silt and clay. Botanical particles of grass, seeds, and insect parts were interspersed with the soil sample along with several cotton fibers. Sands, when present, consist of mica minerals, angular quartz, potassium feldspars, zoned plagioclase feldspars and calcite.

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Feldspar minerals mounted in Cargille dispersion liquid, RI: 1.55. Each division = 6.7 micrometers. Left image in plane polarized light (PPL), right image in crossed polarized light (CPL)

Phytolith, a silica particle from a decayed plant. Decayed plant tissue in soil. Each division = 6.7 um

Quartz grain (CPL), Each division = 6.7um Plant debris, approximately 15 X magnification.

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APPENDIX C: CLIMATOLOGICAL DATA

Temperatures for the month of August of 2011 and 2012 from the Missoula International Airport, 1 mile from the research area. SS1 and SS2 were placed on August 1, 2011. SSC was placed on August 1, 2012:

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## APPENDIX D: TOTAL BODY SCORE (TBS) USING MEGYESI ET AL. (2005) ON SS1, SS2, AND SSC

**Total Body Score (TBS) Using Megyesi et al. (2005) on SS1, SS2, and SSC**

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## APPENDIX E: ENTOMOLOGY IDENTIFICATION FROM Dr. Ralph E. Williams

Entomology Identification from Teresa White Collection
by
Dr. Ralph E. Williams

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