The Postmortem Interval: A Systematic Study of Pig Decomposition in West Central Montana

Hillary Renee' Parsons

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THE POSTMORTEM INTERVAL: A SYSTEMATIC STUDY OF PIG
DECOMPOSITION IN WEST CENTRAL MONTANA

By

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Bachelors of Science, Montana State University, Bozeman, Montana, 2003

Thesis
presented in partial fulfillment of the requirements
for the degree of

Master of Arts
in Anthropology, Forensic Option

The University of Montana
Missoula, MT

May 2009

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The postmortem interval (PMI) is an important piece of information used by forensic and criminal investigators to help investigate crimes and other unattended deaths. Time since death estimations assist law enforcement in providing a reference with which to compare a suspects alibi, identify victims of crime, and solve cases. Studies of decomposition have been conducted at the University of Tennessee’s Anthropological Research Facility in Knoxville, TN; however, decomposition at high altitude climates characterized by colder temperatures and arid conditions is poorly understood. Further, the lack of postmortem interval studies in west central Montana has hindered the investigation and identification of recovered individuals in our area.

Using pigs as proxies for human cadavers, the goal is to observe the rates of decomposition to help estimate the postmortem interval. This project provides information on how the rate of decomposition of two pigs is affected by the climate and insect activity of west central Montana in August and October; late summer and early fall, respectively. The unique climate of west central Montana produces slower decomposition rates that differ significantly from those observed in Tennessee and elsewhere in the United States. The use of accumulated degree-days (ADD) to estimate the postmortem interval reveals accurate time since death estimations and consistency with previous PMI studies despite significant differences in climate and weather patterns.

This project is the first of a series of decomposition research projects that UM master and doctoral student in the anthropology department will conduct in order to systematically document the process of decomposition in west central Montana.
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Chapter 1: INTRODUCTION

Forensic anthropologists are often asked by medicolegal authorities to help estimate the time since death, or the postmortem interval (PMI). The postmortem interval is an important piece of information used by forensic and criminal investigators to investigate crimes and other untimely deaths. Time since death estimation provides a measurable date to assist law enforcement in providing a reference point to evaluate a suspect’s alibi, identify victims of crime, and solve cases. Rates of decomposition are influenced by a variety of factors including, but not limited to, the conditions of the remains (Love and Marks, 2003), depositional setting, (Mann et al., 1990) temperature, (Mann et al., 1990) humidity, (Mann et al., 1990) insect activity, (Rodriguez and Bass, 1983) carnivore activity, (Mann et al., 1990; Love and Marks, 2003) and animal scavenging (Mann et al., 1990). In order to better understand these variables, large-scale studies of decomposition have been conducted at the University of Tennessee’s Anthropological Research Facility located in Knoxville, Tennessee and limited studies have occurred in other areas. However, decomposition in high altitude climates characterized by colder temperatures and more arid conditions in the United States is poorly understood due to a lack of data. Further, the lack of postmortem interval studies in west central Montana have hindered the investigation and identification of recovered individuals in this geographic area.

The goal of this research is to systematically observe rates of decomposition for estimating the postmortem interval by using pigs as proxies for human cadavers. This study will provide information on how the rate of decomposition of two pigs with deposition dates in August and October is affected by the climate and insect activity of
west central Montana. The season dictates variables such as temperature and precipitation that affect the rate of decomposition and the extent of insect activity. Specifically, this project seeks to determine how ambient temperature, weather conditions, and insect activity affect the rate of decay in pig carcasses placed on the ground surface in the diverse climate conditions in this region. It is expected that the unique climate of west central Montana will produce time since death estimations that differ significantly from those observed in Tennessee and elsewhere in the United States.

The author proposes two hypotheses for this study. The first hypothesis states that decay rates in areas characterized by cooler ambient temperatures and low humidity, such as west central Montana, will be slower than decay rates of regions characterized by hot and humid temperatures, such as Tennessee or hot and dry regions such as the American southwest. The second hypothesis posits that the use of accumulated degree-days (ADD) to predict the date of death will provide incorrect estimation of the dates of death when applied to individuals in climatic areas such as west central Montana due to long periods of decomposition stasis caused by long winters and heavy snowfall.
Chapter 2 : LITERATURE REVIEW

Understanding the process of decay requires the evaluation of many fields of study. The events that occur to an individual after death, taphonomy, and the processes that occur as a result of death, biology, are investigated in this review. Since this study emphasizes the importance of regional climatic variation, previous studies of decay from the mountain west, Tennessee, Arizona, and British Columbia are reviewed. The evaluation of decomposition in diverse climates serves as a source of comparison and assessment of the variables and differences associated with rates of decay in climatically diverse regions. An established method for estimating the postmortem interval in other climatic regions is called accumulated degree-days (ADD). ADD is described as the method of analysis in this study. Finally, the use of forensic entomology to evaluate insect succession patterns observed in decomposition studies is discussed as a valuable tool for the assessment of insect succession patterns in our region.

Taphonomy

Taphonomy is the discipline that investigates and interprets all activities that occur to remains after death. It was originally defined as the study of death assemblages and the laws of burial (Efremov, 1940). The term has undergone a series of modifications including Bonnichen’s (1989) definition where taphonomy is viewed from a site formation perspective as the accumulation and modification of osteological assemblages. Early studies of taphonomy were derived from the disciplines of paleontology and archaeology where the focus remained on the fossil record with little consideration of biological decompositional processes (Haglund and Sorg 1997).
However, the broad scope of taphonomy allows for the analysis of forensically relevant cases utilizing the expertise of forensic anthropologists. According to Haglund and Sorg (1997) forensic investigators are interested in the perimortem interval which includes events that occur around the time of death, and the postmortem interval, the time that exists between death and recovery of remains. The analysis of decay rates in soft tissue is an area of taphonomy where forensic anthropologists can provide expertise in time since death estimations, cause and manner of death, and the identification of factors relating to the decomposition and preservation of human remains (Haglund and Sorg, 1997.) Forensic taphonomy, therefore, focuses on events of the recent past and seeks to reconstruct, collect, and analyze data from disposed remains. Haglund and Sorg (1997) provide a definition of forensic taphonomy that is useful in forensic anthropology contexts and will be used as the basis for the present study. Taphonomy “refers to the use of taphonomic models, approaches, and analyses in forensic contexts to estimate the time since death, reconstruct the circumstances before and after deposition, and discriminate the products of human behavior from those created by the earth’s biological, physical, chemical, and geological subsystems” (Haglund and Sorg, 1997 p.3).

Limited research has been devoted to the taphonomy of contemporary human remains, with the exception of the Anthropological Research Facility at the University of Tennessee, despite the medicolegal importance of relevant studies. Cultural and ethical limitations placed on the scientific investigation of death (Smith, 1986) limit research opportunities.
Biological Decay

The increase in collaboration between forensic anthropologists and the medicolegal system allows for the expansion of knowledge regarding decompositional processes. Decomposition is a progression of the breakdown of microbiological materials from fresh to skeletal remains to the breakdown of skeletal remains (Love and Marks, 2003). According to Aufderheide (1981) and Nielsen et al. (1994) the physical reduction of remains includes the decomposition of external remains and internal remains. The external environment reduces the external remains while the internal environment is reduced due to cell death and proliferation of colonic microbial activity (Coe, 1993; Gill-King, 1997; Clark et al., 1997).

Love and Marks (2003) describe the basic processes of decomposition including autolysis and putrefaction. Autolysis is the earliest biochemical process of decomposition causing tissue death and producing byproducts that result in the progression of putrefaction. The culmination of the decompositional process at this level results in pale tissue color. Additional morphological changes include the breakdown of cells between the epidermis and dermis resulting in the removal of the epidermal layer, known as skin slippage.

Other external observational changes include algor mortis, livor mortis and rigor mortis. Algor mortis is the cooling of the body to ambient temperature. The human body maintains a core temperature of 98.6°F. At death, the body typically cools at a rate of 1.5°F per hour (Henssge et al., 1995), however bodies do not cool at consistent rates and
as a result, algor mortis is not a reliable indicator of time since death. Livor mortis is the pooling of blood in the capillaries due to gravitational forces and can be seen between one and two hours postmortem. Lividity can become fixed between eight and twelve hours postmortem (Coe, 1993; DiMiao and DiMiao, 1989; Clark et al., 1997) and can no longer be used to estimate the postmortem interval. Rigor mortis is the stiffening of muscles resulting from the binding together of muscle fibers dependent on environmental factors. Rigor mortis develops one to two hours postmortem and completes at twelve hours (DiMiao and DiMiao, 1989; Spitz, 1993; Knight, 1996; Clark et al., 1997).

Putrefaction is described as the destruction of the soft tissues and internal bacteria as a result of the release of nutrients from the autolyzed cells and the loss of intercellular pH (Love and Marks, 2003; Vass et al., 2001). The cecum, located in the lower right abdominal cavity hosts the largest bacterial population in the body. The location of the cecum allows for early detection of putrefaction (Knight, 1996; Spitz, 1993) and putrefaction can be seen by the greenish color that the skin acquires. As a result of the bacterial proliferation, hydrogen sulfide gas is released and reacts with iron in the bloodstream. This reaction causes discoloration of the dermis layer over the cecum and eventually spreads through the entire body causing a “marbled” skin surface. Gases that remain in the abdomen cause the abdomen to bloat. The release of volatile fatty acids as by-products of the gut occurs at this time (Vass et al., 2002) and active decay begins. Active decay occurs after the purging of the gases from the body and muscle tissues, made of proteins, begin to break down and produce additional volatile fatty acids.
Relevant Studies

Numerous studies at the Anthropological Research Facility at the University of Tennessee have documented rates of decomposition in various death scene situations. These studies are valuable to understanding the factors contributing to the rates of decay in environments similar to that of east Tennessee. After eight years of decomposition research at the University of Tennessee, Mann et al. (1990), emphasize the variability in decompositional processes and the variable rate at which bodies decompose. Bass (1997) states, “the major factor in decomposition is temperature; bodies decay much faster in summer than they do in winter” (p.181). In warm to hot weather conditions, Mann et al. (1990) describes nearly complete skeletonization to complete skeletonization of human bodies in two to four weeks. However, the most difficult time to estimate the postmortem interval is during months where temperature fluctuates from warm to cold. Humidity is also an important contributor in the decay of individuals as the mummification of skin decreases insect activity (Mann et al., 1990). In general, as temperature and humidity surrounding a body increase, the faster it will decompose. Insect activity contributes to the rate of decomposition and increases during warmer months. In Tennessee, Mann et al. (1990) describe an increase in the number and types of insects visiting cadavers during the warmer spring and summer months and a decline in the number and types of insects in the fall and winter months.

Studies conducted by Galloway et al. (1989) provide an example of how the process of decomposition in hot arid climates characterized by the American southwest differs from studies conducted at the University of Tennessee. In this retrospective study,
468 cases were selected from the Human Identification Laboratory of the Arizona State museum at the University of Arizona. The results showed that temperature and humidity are the primary factors involved in the decomposition process in desert environments. The hot temperatures and low humidity allows for the rapid removal of moisture from the body to the atmosphere causing the body to mummify. The rapid rate of dehydration decreases the amount of insect activity on the body due to a decline in odor emulating from the body and the inability of insects to feed on the remains. Insects must lay eggs in the beginning stages of decay or the surface of the body will be too dry to carry out insect life stages. Larvae have a better chance of survival on the internal tissues of the body as they are more protected from the elements and tissues soften due to autolysis. Bass (1997) explains, “maggots do not like sunlight, and if there is no overhead covering, they will leave the skin as an umbrella to protect them from the sunlight” (p.182). Galloway et al’s. (1989) study shows the differences in variability of decomposition that exists in a climate that differs significantly from that of Tennessee.

Studies of decomposition in cold and arid environments will differ from those reported in Arizona and Tennessee, however, these types of studies have been limited and more often remain unpublished. Recent publications of cold weather decomposition include Komar’s (1998) review of cases from the Alberta Medical Examiner’s Office in Edmonton, Canada, and Bunch’s (2009) observational study of pig carcasses near Oswego, New York. Studies of carrion insects have garnered a number of publications in forensic entomology; however, studies of the impact of these insects in cold weather climates and arid environments are limited. Preliminary studies conducted by Terneny (1997) in Missoula, Montana and Barnes (2000), Wagster (2007), and Gonder (2008) at
the Lubrecht Experimental Forest located approximately 35 miles from Missoula, Montana yield valuable information about the decomposition process in this area, but to date, no systematic study utilizing human remains exists.

Komar (1998) reviewed cases of advanced decomposition from the Medical Examiners office in Edmonton, Alberta in an attempt to establish methodological parameters for field experimentation in cold temperature climates. The data set included 20 individuals discovered in various states of decomposition in a variety of deposition environments. The stages of decomposition were recorded for each individual in autopsy notes having moderate decomposition, advanced decomposition, partial skeletonization, and complete skeletonization. Results showed that in the summer months, remains could be reduced to skeletal elements in less than six weeks. Rates of decomposition slowed during the winter with one case reaching skeletonization in four months with the mean temperature of -7.1°C. Entomological information was not recorded in the autopsy reports and the role of entomology in the decomposition process in this study is not known.

Bunch (2009) conducted a qualitative observational study on three pigs (*Sus scrofa*) at the Rice Creek Field Station outside of the State University of New York at Oswego. The climate at Oswego is characterized by cold winters with regular snowfall. The project utilized child-size (35-40 lb) specimens placed in three microclimates inside enclosures to prevent large-scale carnivore scavenging. The stages of decomposition were described as fresh, discoloration, bloating, skeletonization, and skeletal decomposition. Results showed varying rates of decomposition between the three specimens in different microclimates with the most advanced specimen (specimen #3)
reaching skeletonization after one year of exposure. The reason for the accelerated rate of decay for specimen #3 is not fully understood. Entomological analysis at specimens 1 and 2 showed presence of insect activity into December when temperatures ranged from 3.3°C to 4.1°C. Insect activity at specimen #3 was lower despite the more advanced level of decay. This study contrasts research in warmer climates and shows a slower rate of decomposition due to lower ambient temperatures and a differential insect succession pattern between specimens.

Terneny (1997) observed rates of decomposition using two pigs (*Sus scrofa*) in Missoula, Montana from April 1996 through April 1997. One pig (160 lbs) was buried while the other (180 lbs) was deposited on the surface. The site was located in a rural area outside of town. The stages of decomposition were developed based on Payne (1965) and described as fresh stage, bloated stage, active decay stage, advanced decay stage, dry stage, and remains stage. Results indicated that the buried remains decomposed at a slower rate than surface remains and that decompositional changes occurred at slower rates than previously reported studies in warmer climates. Terneny observed the carcass in the fresh stage for 2 days, the bloat stage for 7 days, the active stage for 66 days, the advanced stage for 26 days, and skeletonization for 262 days. Terneny (1997) noted with the surface deposition that bloat occurred, deflated, and occurred once again with an increase in ambient temperatures. Insect activity was reportedly higher on hot sunny days and lower on cooler days.

Barnes (2000) conducted an observational entomological analysis of two 180 lb pigs (*Sus scrofa*) at the University of Montana’s Lubrecht Experimental Forest located approximately 48.3 kilometers from Missoula, MT from June 1999 through December
1999. Both specimens were deposited on the surface while one was burned and the other was set as a control. The results showed decay rates and larval development were comparable to a study conducted by Dillon (1997) in British Columbia. Dillon (1997) conducted insect succession studies on sunned and shaded pig carrion in Vancouver British Columbia. Dillon placed animal carcasses in a heavily wooded area similar to that of the Lubrecht Experimental Forest. Barnes attributed the similarities of the insect succession patterns in their respective studies to the similar Douglas fir and Douglas fir/ponderosa pine Rocky Mountain biogeoclimatic zone. The insect succession patterns between the burned specimen and the control specimen in Barnes’ study were similar with Phormia regina and Lucilia illustris being the most dominant species in both specimens. Barnes observed the carcass in the fresh stage for 1 day, the bloat stage for 7 days, 4 days in the decay stage, 23 days in post-decay stage, and 186 days in the remains stage. Barnes (2000) was not able to make an accurate comparison to Terneny (1997) research on pig carcasses due to differences in high versus low elevation depositions, generalized insect identification, and lack of climatological data in Terneny’s research.

Wagster (2007) observed four wolf carcasses during winter at the University of Montana’s Lubrecht Experimental Forest to determine the rate of decay and presence of insect activity during the freeze-thaw processes. Wolves’ numbers 1 and 2 were placed in June and decayed in a predictable manner. Wolf numbers 3 and 4 were placed in September. Wolf 3 decayed at a slower than expected rate while wolf 4 decayed at a predictable rate. Despite differential rates of decay, each carcass exhibited maggot activity during the cold months of winter between periods of snowfall and snow melt. The variable temperatures exhibited during the 2006-2007-winter season allowed the
opportunity for insect activity. As temperatures increased, insect larvae emerged. An
increase in odor from the carcasses was also associated with warmer temperatures in the
winter. This may also have an effect on insect activity as previously mentioned by
Galloway et al. (1989). Wagster (2007) concluded that the presence of maggot activity
during the freeze-thaw process demonstrates that carcasses can remain in an active stage
of decomposition during winter months.

Gonder (2008) systematically observed rates of decay in wolf, bear, deer, and
mountain lion carcasses at the University of Montana’s Lubrecht Experimental forest for
a period of two years. The goal of her research is to assist wildlife law enforcement
officers regarding postmortem interval estimations on non-human specimens to track
poaching behaviors characteristic of the mountain west. Her study includes several areas
of taphonomic research including observational documentation of desiccation of remains,
ambient temperature readings, ambient humidity readings, carcass temperature readings,
and insect succession patterns. Gonder (2008) observed slower rates of decay compared
to studies conducted in warm and humid environments but found consistency and
predictability of decay rates and insect succession among carcasses placed at Lubrecht for
the duration of her study. Her research is most equivalent to the current study as similar
methods of data collection were employed.

Micozzi (1997) describes how the freezing and thawing of soft tissue can affect
the rate of decomposition. Freezing will preserve soft tissue but when thawed may
accelerate certain decompositional changes and slow others. Decker (1978) outlines the
effect of cold temperatures on the decomposition process noting that putrefaction does
not occur below 4°C and freezing stops bacterial growth preserving tissue. Micozzi
(1986) found that animals previously frozen and thawed appeared to decompose from the “outside in” with decay as a result of the soil organisms. Unfrozen specimens appeared to decompose from the “inside out” due to cellular breakdown and putrefaction. He found that frozen and thawed animals were more susceptible to insect activity and microorganisms from the outside with aerobic decay of the external surfaces. Animals that were fresh exhibited more anaerobic decay (putrefaction) and less external decay.

Accumulated Degree Days

Accumulated degree days (ADD) is the sum of consecutive average daily temperatures to correlate stages of decomposition. (Vass et al., 1992; Love and Marks, 2003; Megyesi et al., 2005). ADD estimations are useful in estimating the postmortem interval because temperature and humidity are more important factors in the decomposition process than time. (Galloway et al., 1989; Vass et al., 1992; Megyesi et al., 2005). Megyesi et al. (2005) scored a sample of 68 human remains cases from varying microclimates based on modified stages of decomposition outlined by Galloway et al. (1989). The decomposition stages were described as: fresh, early decomposition, advanced decomposition, and skeletonization. Each stage was further scored with a beginning value of “1” indicating the fresh stage of decomposition and increasing for each development of decomposition. The total point value represents the total amount of decay. The scoring method was separately conducted for three anatomical regions of the body to compile a total body score (TBS) for the individual. The observed decay stage was directly compared to the accumulated degree-days. The ADD represents the heat energy units available to drive a biological process. A base temperature is the temperature at which the biological processes stop. Megyesi et al. (2005) uses 0°C as the
base temperature for the study because biological processes halt at freezing temperatures. Daily temperatures below 0°C were scored as zero because negative temperature data will subtract from the overall ADD estimation. Megyesi et al. (2005) found the postmortem interval estimation to be valuable when applying a total body scoring method as a quantitative approach to qualitative variables. This study found that accumulated degree-days in combination with elapsed time accounted for over 80% of the observed variation of decomposition. However, case #27 from Jackson, Indiana and case #53 from Missoula, Montana were outliers in the data set and removed from the predictive equations. The case from Missoula, Montana “is most likely an outlier due to other environmental factors specific to Montana that were not directly controlled for in this study such as altitude or rainfall” (Megyesi et al., 2005 p 626).

**Forensic Entomology**

Forensic, or medicolegal entomology is defined as, “the study of insects associated with carrion in order to determine the time of death” (Anderson and VanLaerhoven, 1996 p.617). Anderson and VanLaerhoven (1996) note that after 72 hours, forensic entomology is typically the most accurate method for determining the time of death.

Insects are often the first to arrive at a death scene and they tend to arrive in a predictable succession, as the different stages of decomposition are appealing to different species. Each geographic region has numerous variables such as insect type and climatic differences that affect the succession patterns. Rodriguez and Bass (1983) in a study conducted at the University of Tennessee on four individuals found that there is a direct
correlation between the rate of decomposition and the succession of insect families and species. Warmer temperatures produced an increase in insect numbers and types and cooler temperatures reduced insect numbers and types. The amount of decay increased with warmer temperatures and increased insect activity whereas; the rate of decay decreased with cooler temperatures and decreased insect activity. Reed (1958) conducted entomological studies on 45 dog carcasses in Knoxville, Tennessee and found that total arthropod populations were greater in the summer and that insect populations were larger in wooded areas. Payne (1965) conducted studies on decaying animals in North Carolina and found,

“A definite ecological succession occurred among the fauna of carrion. Each stage of decay was characterized by a particular group of arthropods, each of which occupied a particular niche. Their activities were influenced by physical properties of carrion, rapidity of putrefaction, time of day, and weather.” (Payne 1965 p. 592-602.)

Blow flies (Diptera) and muscid flies are most often the first insects observed on carrion (Haskell et al., 1997; Kulshrestha and Chandra, 1987; Rodriguez and Bass, 1983; Shean et al., 1993). In warm temperatures, Diptera will be on the body within minutes of deposition and begin oviposition. Areas of the body that are first colonized by insects include the eyes, mouth, nasal cavity, anus, vagina, and areas of trauma (Sledzick, 1998). The nose and mouth emit odors that attract flies and are often the first areas where colonization occurs. Eyes are colonized because of high levels of moisture and protection the eyelid provides. The vaginal or anal openings and penis attracts flies with colonization of eggs and larvae. Haskell et al. (1997) notes that there may be a delay in fly colonization of the pelvic region as much as 12 to 36 hours of age. Flies and larvae
attracted to areas of the body lacking natural orifices may be evidence of trauma where openings of the skin have been produced unnaturally.

Haskell et al. (1997) states that among the 17,000 species representing 107 families of Diptera, approximately 100 flies from 18 families correspond to species associated with decomposition. The family of Calliphoridae represents four major tribes of flies called, bluebottle, greenbottle, screwworm flies, and black blowflies. Bluebottle flies are large and adapted to cooler climates and are commonly encountered in the spring and fall. Greenbottles are small flies found in midsummer. Screwworm flies are tropical and require warm temperatures for development. Black blowflies are dark blue to olive green, smaller than bluebottles and found in periods of moderate temperature.

Greenbottle flies comprise the tribe Luciliini and the Lucilia species typified by *Lucilia Illustris* (Meigen) and are often found in rural environments. The tribe Phormiini contains the commonly encountered species *Phormia regina* (Meigen). This species is found in many parts of the United States and occurs when temperatures are above 16°C. *Phormia terraenovae* (Robineau-Desvoidy) is common in Alaska and the Pacific Northwest during cool periods of the year and found at higher elevations in the Rocky Mountains and Canada. The bluebottle flies are from the tribe called Calliphorini and found in the northern United States. They are found on remains during the early to mid spring. Screwworms are also a member of the Calliporini tribe and attracted to carrion during midsummer in northern and central parts of the United States.

The Dipteran life cycle is important to estimating the postmortem interval. The stages of development have been evaluated with respect to differing temperature and environmental studies. According to Haskell et al., (1997) the stages of insect
development can accurately determine the PMI if environmental conditions and species are identified correctly. The blowfly life cycle begins with the oviposition of eggs into eyes, mouth, and nasal passages where moisture and protection from the sun is optimal. Within hours (dependent on species and ambient temperatures) the eggs hatch and produce the first instar of larvae. This stage is difficult to observe, as the larvae are only two millimeters in length, exhibit a darkened appearance and have limited mobility. The second instar begins when the larvae shed their exoskeleton and persists for only 8-12 hours. During this stage, the larvae are four to six millimeters in length and are feeding more heavily on the carcass. The third instar begins when the second instar molts. The increased development causes the larvae to feed more quickly and in larger quantities and maggots will be observed in masses on the body. Feeding will end when the maggot acquires the fat needed to pupate. The larvae will migrate off the body and find a sheltered location to pupate. In the first stage of pupation, the exoskeleton of the third instar larvae forms to become the puparium. As pupation progresses, the puparium hardens and changes color from a maroon, to dark brown, to black. This color change can be used to age puparia. After several days, the fly will emerge from the puparium and will develop into an adult fly in three to five days.

Haskell et al. (1997) identifies several flies that are typically associated with decaying remains. Sarcophagidae (flesh flies) deposit the first instar on the body instead of laying eggs. Phoridae (humpbacked fly), Sepsidae (black scavenger flies), Sphaeroceridae (small dung flies), and Stratiomyidae (soldier flies) are other flies commonly found on decaying remains. In the family Piophilidae, Piophila casei (cheese-skipper) are found in advanced decomposition stages and when in the larvae stage, they
jump when threatened or disturbed.

Beetles of the order Coleoptera are attracted to carrion to feed on the eggs and larvae of the flies. The silphids (carrion beetles), dermestids (hide beetles), Nitidulids (sap beetles), and clerids (checker beetles) feed on the carrion. In early stages of decomposition with warmer temperatures, families of the Staphylinidae (rove beetles), Silphidae (carion beetles), Histeridae (hister beetles), and Hydrophilidae (hydrophilid beetles) are found on the body.

Other insects found at the site of decomposing carrion include Hymenoptera (bees, wasps, ants), Lepidoptera (butterflies and moths), Hemiptera (true bugs), Dictyoptera (cockroaches), and Acari (mites) of the class Arachnida (spiders ticks and mites). Wasps and ants are predators that feed on fly eggs and insect larvae and bees feed on the fluids from the carrion.

Forensic taphonomy is a growing field that requires the investigation of taphonomic processes affecting deceased individuals in a variety of environmental settings. Taphonomic studies in west central Montana will aid in the understanding of the postmortem interval for climates characterized by cold and arid weather conditions. The considerable fluctuations in ambient temperature that occur each day and the extreme changes in temperature and climatic conditions between seasons in this environment warrant studies of this kind to aid in the estimation of the postmortem interval. This study serves to provide a comprehensive systematic approach to observe the rates of decomposition in this variable environment and provide law enforcement and death investigators with information regarding the postmortem interval.
Chapter 3: MATERIALS AND METHODS

To study the process of decomposition, a research facility was set up to contain 2 test subjects (*Sus scrofa* 1 and 2). The sites were visited regularly to observe the decomposition process, evaluate the rate of decay, collect insect samples, and maintain the facility. Detailed notes and photographs were taken during each site visit to document any changes to the specimens, insect activity and weather patterns. Temperature data collected from a Hobo Pro Series data logger and the Greenough Hill weather station were used to calculate the accumulated degree-days (ADD) to estimate the postmortem interval. All insects collected were identified and analyzed for patterns of insect succession.

**Study Area**

The study site for this research project is situated within the Lubrecht Experimental Forest located in Greenoughn approximately 48.3 kilometers east of Missoula, Montana. The geographical area surrounding Missoula is best described as west central Montana. The Lubrecht Experimental Forest consists of 28,000 acres of zoned and managed land for recreation, research, conservation and range management. The research site is located along an unimproved secondary road approximately 2.41 kilometers from the Lubrecht Experimental Forest headquarters off of Highway 200 very close to the location of Gonder’s (2008) research site. The elevation of the site is approximately 4,300 feet. Vegetation of the area includes the forest canopy cover of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudostuga menziesii*). This canopy comprises approximately 30% of the total overstory (Barnes, 2000; Gonder, 2008).
understory vegetation includes snowberry (Symphoricarpos duhamel), ninebark (Physocarpus maxim), bearberry (Arctostaphylos uva-ursi), and other mountain grasses. The terrain is flat and located on the eastern slope of the mountain (Figure 1).

Fauna native to the area includes large-scale carnivores such as black bear, grizzly bear, mountain lion, and wolf. Small-scale scavengers include squirrels, and mice. Large herbivores include elk and deer. Cattle from the Paws Up resort ranch located approximately 2 kilometers from the research facility frequently roam and graze on the vegetation in the area.

Figure 1: View of the perimeter of the research facility
Security

A bear management plan modeled after Gonder (2008) was drafted (Appendix A) and turned into Frank Maus, Director of the Lubrecht Experimental Forest to ensure the proper wildlife protocol is followed during site visits and that bear activity at the site is minimized. Each researcher is required to carry a canister of bear spray for protection during site visitation. Following Gonder’s (2008) design, two enclosures made from chain link fence panels measuring 6x4x4 (Figure 2) and 16x6x4 were built to encase each specimen to prevent large-scale carnivore activity and scavenging. Figure 3 shows both enclosures. The enclosures were built to withstand damage caused by bears and reinforced at the corners by 5.5 foot steel fence posts and topped with livestock fence panels. These panels serve to deter entrance to the enclosure from above by carnivores and avian predators and scavengers.

Figure 2: 6x4x4 enclosure with locations of 4 pit traps and Hobo Pro Series data logger
For added security, each enclosure was wired for electricity using standard electric fence powered by an electric fence battery conducted through a Gallagher electric fence energizer. For the winter season, a deep cycle RV battery replaced the electric fence battery as it has a longer life cycle and can withstand colder temperatures. The fence was maintained and checked for voltage at each site visit to ensure a constant 6000-volt charge. The perimeter of the enclosure was maintained to prevent electric current failure and to ensure safety of recreational visitors to the area.

**Test Subjects**

For this study, two pigs (*Sus scrofa*) were used as proxies for human cadavers.
Pig specimens are an appropriate substitute for human specimens because they share many biological characteristics with humans. Similarity of organ tissues and structure as well as comparable skin thickness, amount of body hair, and gut fauna make pigs ideal for studies of decay. Many previous surface and burial decay studies utilize pigs for test specimens as proxies for human cadavers including studies conducted by Payne (1965), Anderson et al. (1996), Dillon (1997), Terneny (1997), Barnes (2000), and Bunch (2009).

*Sus scrofa* specimen number 1 (SS-1) was acquired from a butcher in Arlee, Montana. Time of death for SS-1 was recorded at 11:35 am on August 6, 2008 by a .22 caliber gunshot wound to the central forehead and a second .22 caliber gunshot wound behind the left ear. SS-1 weighed 84.1 kilograms (185 pounds) and measured 134.62 centimeters (53 inches) from the snout to the rump. SS-1 was placed at the Lubrecht research facility at 3:35pm on August 6, 2008. Weather conditions were hot and dry and the ambient temperature at the time of placement was 35 degrees Celsius (95 degrees Fahrenheit). A remote probe meat thermometer was placed between the ground and the left abdomen of the specimen to record surface-to-body temperature.

*Sus Scrofa* specimen number 2 (SS-2) was acquired from private rancher located in Inverness, Montana. Time of death for SS-2 was recorded at 12:15pm on October 13, 2008 by a .22 caliber rifle wound to the central forehead and a second .22 caliber rifle wound behind the left ear. SS-2 weighed 72.7 kilograms (160 pounds) and measured 137.16 centimeters (54 inches) from the snout to the rump. SS-2 was placed at the Lubrecht research facility at 5:10pm on October 13, 2008. Weather conditions at the time of placement were cool and moist and the ambient temperature was 8.77 degrees Celsius (47.8 degrees Fahrenheit). A remote probe temperature meat thermometer was
Data Collection Protocol

A Hobo Pro Series Weatherproof Data Logger was placed in the southwest corner of the enclosure containing SS-1. The data logger was programmed to take the daily high and low temperatures as well as temperature and humidity readings at regular three-hour intervals at 12:00am, 3:00am, 6:00am, 9:00am, 12:00pm, 3:00pm, 6:00pm, and 9:00pm. The temperature readings were calibrated with the Road Weather Information system (RWIS) local weather station located at Greenough Hill approximately 3.2 kilometers from the research site. Data for SS-1 was visually observed and collected once a day for the first 15 days of decomposition due to the high temperatures and rapid rate of decay. As decay slowed and entered the advanced stage, site visits decreased to four days a week for two weeks, three days a week for two weeks, and once a week until December 7, 2008. This visit was the last site visit prior to snowfall. The final site visit was conducted on April 12, 2009.

Data collected during each site visit included photographs of the carcass from each direction around the perimeter of the enclosure and photographs of the carcass in each direction inside the enclosure. Temperature data collected included the ambient temperature, axillary temperature from the right forearm, and ground surface to body temperature using the remote probe meat thermometer.

Four pit fall traps were dug in each cardinal direction 30.5 centimeters (12 inches) from the carcass. Each pit fall trap was created by digging a circular hole approximately
12.7 centimeters (5 inches) in diameter and approximately 20.32 centimeters in depth (8 inches) into the ground. A standard 2 liter soda-pop bottle was cut at the top to create a funnel from the neck. A cup filled with RV antifreeze was placed inside the bottle and the funnel inserted upside down in the bottle. Each pit fall trap was covered with aluminum cross hatches and topped with a circular metal cover to prevent precipitation from entering the trap. Figure 4 shows the placement of each pit trap in relation to the specimen inside the enclosure.

Figure 4: Top view of 6x4 enclosure with specimen, pit traps, data logger, and temperature probe

Insect and larvae samples were collected using a sweep net and pit fall traps. The insects collected from the sweep net were killed using vapors from an ethyl alcohol soaked cotton pad placed in the bottom of a mason jar. Each jar was labeled with the specimen number, date of collection, and time of collection. Insects crawling on the ground fall into the traps and are collected by filtering out the antifreeze. Insect
33 specimens from each trap were bagged separately and labeled with the specimen number, date of collection, time of collection, and location of collection. All insects were refrigerated until analysis. Insect larvae samples were collected where major masses existed on and around the carcass. Using soft forceps, a small sample from each mass was collected and labeled in the same as pit fall trap collections.

Visual observations were recorded using a digital voice recorder and included general descriptions of weather activity, shading and sunning of carcass, odor of carcass, level of activity and description of decay of the carcass, insect and larvae activity, and any other activity associated with decay and environmental conditions. All data was transcribed on a carcass data form (Appendix B).

Data collection for SS-2 followed the same protocol as SS-1, however, due to the cold temperatures and a reduced rate of decay, site visitations were less frequent. SS-2 was visited every day for the first two weeks and 4 days a week for 7 weeks until December 7, 2008. This visit was the last site visit prior to snowfall. The final site visit was conducted on April 12, 2009.

Insect identification included the classification of the order and family of each forensically relevant specimen. Genus and species identifications were made when possible. Insects recognized to be incidental with little forensic relevance were noted but not identified specifically. Insects were identified under microscopes at the University of Montana’s Emlen Entomology Lab.

**Descriptions of Decay**

The decomposition of each carcass was observed to occur in four stages following
Megyesi (2005). Megyesi modified Galloway et al.’s (1989) categories intended to describe the process of decomposition in hot and arid environments. The four categories of decomposition are described as: fresh, early decomposition, advanced decomposition, and skeletonization.

**Fresh stage**

The fresh stage is characterized as the beginning of decomposition immediately following death. The fresh stage continues until the first signs of bloating begin, which is highly variable depending on the external environmental temperatures and conditions. There are relatively few external changes occurring during the fresh stage and the odor associated with the remains is the natural smell of the body. Livor mortis, the pooling of blood; rigor mortis, the stiffening of limbs; and algor mortis, the cooling of the body; are processes of decay that occur during the fresh stage. Insects can arrive on the body within minutes given warm enough temperatures to support insect activity. Dipterian insects including Calliphoridae, Muscidae, and Sarcophagidae are typically the first to arrive on a body during the fresh stage (Payne, 1995) and will oviposit in the natural openings of the body such as the ears, eyes, nose, mouth, anus, and vaginal regions as well as in any areas where the skin is broken (Catts and Haskell, 1990).

**Early decomposition**

In early decomposition the skin begins to change color and exhibits a marbling effect. Bloating occurs in the region of the abdomen and the skin begins to take on a green discoloration. During the bloating period, the body begins to purge decompositional fluids and blood is released from the nose (Terneny, 1997). After the
bloat period abdominal gasses will release and the abdominal cavity will decrease in size. The skin will darken from the green hue to a brown and/or black appearance (Megyesi, 2005). Bloating can occur rapidly in warm temperatures and last 2-5 days, however, if the temperatures are cooler, the carcass may experience numerous cycles of bloat and deflation (Johnson 1975). Tissues of the limbs will exhibit drying and have a leathery appearance and discoloration and darkening of the skin occurs particularly around the edges of the extremities (Megyesi, 2005). Dipterian insect activity is high during this phase of decomposition and flies continue to oviposit on the body.

**Advanced decomposition**

Once bloating has ended, the tissues will sag and the abdominal cavity will have a sunken appearance. The tissues of the eyes and throat will have a caved in appearance and the skin will take on a “wet” appearance where the liquefaction and disintegration of tissue begins (Payne, 1965). The abdominal cavity will remain moist while other areas of the body such as the extremities will exhibit mummification or partial skeletonization depending upon external environmental conditions (Megyesi, 2005). The skin will change colors periodically and range from dark colors such as brown, red, and black to light colors such as light brown, tan, and orange. The odor of decay during this phase is strong and putrid and can be detected over long distances.

This stage exhibits a significant increase in insect activity and species diversity. In addition, insect larvae appear in masses. Insect larvae consume the flesh and burrow inside the carcass for protection and feeding. Other insects such as beetles and spiders make their way to the carcass either to feed on the carcass itself or on the larvae and other
insects inhabiting the carcass. Staphylinidae (rove beetles), Histeridae (hister beetles), Silphidae (carrion beetles), Sepsidae (black scavenger flies), and Phalangidae (daddy-long legs) inhabit the carcass for the first time (Payne, 1965). In the later phases of advanced decomposition, arthropods migrate from the body and burrow in the soil (Reed 1958).

**Skeletonization**

Early phases of this stage are identified when the majority of soft tissue has decomposed or when mummified tissue begins to break down to reveal bone (Megyesi, 2005). Odor is minimal and takes on a musty or moldy smell. Insect activity is significantly reduced and characterized by species that remain to feed on the decayed material. Millipedes, Dermestidae (hide beetles), Nitidulidae (sap beetles), Cleridae (checkered beetles), mites and ants are present during this phase of decomposition (Payne, 1965).

Later phases of skeletonization include bones that are dry but retain grease and bones that are completely dry with little to no soft tissue adhering. Skeletonization can take place as quickly as two weeks in hot and humid environments but take much longer to reach in areas characterized by cold and dry climates.

**Accumulated Degree Days**

In order to calculate the time since death for our two specimens, Megyesi’s (2005) method of estimating the postmortem interval using accumulated degree days (ADD) was employed. Each carcass was scored using each of the four stages of decomposition as a
guide. Each stage is divided into numerical categories that are used to score remains, effectively transforming qualitative data into quantitative data. The categories within each stage describe the appearance and general characteristics of the remains. The scoring method begins by assigning a point value beginning with the number “1” (fresh) and increasing one point for each progressive phase. Since decomposition is not uniform in all parts of the body, three major areas of the body (the head and neck, the trunk, and the limbs) are scored independently of one another. The stages of decomposition for each anatomical area are slightly different to accommodate their differential rates of decay. The sum of the total points represents the total amount of decomposition exhibited and is called the total body score (TBS). The scoring method for each anatomical area is outlined in Tables 1-3 taken from Megyesi (2005). Table 1 describes categories and stages of decomposition for the head and neck. Table 2 describes categories and stages of decomposition for the trunk. Table 3 describes categories and stages of decomposition for the limbs.
<table>
<thead>
<tr>
<th>Table 1: Categories and stages of decomposition for the head and neck</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fresh</strong></td>
</tr>
<tr>
<td>(1pt) 1. Fresh, no discoloration.</td>
</tr>
<tr>
<td><strong>Early Decomposition</strong></td>
</tr>
<tr>
<td>(2 pts) 1. Pink-white appearance with skin slippage and some hair loss.</td>
</tr>
<tr>
<td>(3pts) 2. Gray to green discoloration: some flesh still relatively fresh.</td>
</tr>
<tr>
<td>(4pts) 3. Discoloration and/or brownish shades particularly at edges, drying of nose, ears, and lips.</td>
</tr>
<tr>
<td>(5pts) 4. Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of the neck and face may be present.</td>
</tr>
<tr>
<td>(6pts) 5. Brown to black discoloration of flesh.</td>
</tr>
<tr>
<td><strong>Advanced Decomposition</strong></td>
</tr>
<tr>
<td>(7pts) 1. Caving in of the flesh and tissues of the eyes and throat.</td>
</tr>
<tr>
<td>(8pts) 2. Moist decomposition with bone exposure less than one half that of the area being scored.</td>
</tr>
<tr>
<td>(9pts) 3. Mummification with bone exposure less than one half that of the area being scored.</td>
</tr>
<tr>
<td><strong>Skeletonization</strong></td>
</tr>
<tr>
<td>(10pts) 1. Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.</td>
</tr>
<tr>
<td>(11pts) 2. Bone exposure of more than half the area being scored with desiccated or mummified tissue.</td>
</tr>
<tr>
<td>(12pts) 3. Bones largely dry, but retaining some grease.</td>
</tr>
<tr>
<td>(13pts) 4. Dry bone.</td>
</tr>
</tbody>
</table>
Table 2: Categories and stages of decomposition for the trunk

**Fresh**

1. Fresh, no discoloration.

**Early Decomposition**

1. Pink-white appearance with skin slippage and marbling present.
2. Gray to green discoloration: some flesh relatively fresh.
3. Bloating with green discoloration and purging of decompositional fluids.
4. Postbloating following release of the abdominal gases, with discoloration changing from green to black.

**Advanced decomposition**

1. Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity.
2. Moist decomposition with bone exposure less than one half that of the area being scored.
3. Mummification with bone exposure of less than one half of the area being scored.

**Skeletonization**

1. Bones with decomposed tissue, sometimes with body fluids and grease still present.
2. Bones with desiccated or mummified tissue covering less than one half of the area being scored.
3. Bones largely dry, but retaining some grease.
4. Dry bone.
Table 3: Categories and stages of decomposition for the limbs

**Fresh**

(1pt) 1. Fresh, no discoloration.

**Early Decomposition**

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

(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, 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 of less than one half that of the area being scored.

**Skeletonization**

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

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

(10pts) 3. Dry bone.

In order to calculate the accumulated degree-days for our specimens the carcasses need to be scored by using the above scoring method. The total body score is used with the equation:

\[
\log_{10}\text{ADD} = 0.002(TBS*TBS) + 1.81 +/\sim 388.16
\]
This equation is simplified to:

$$ADD = 10^{(0.002 \cdot \text{TBS} \cdot \text{TBS} + 1.81)} + \cdot 388.16$$

where 388.16 is the standard error of the regression (Megyesi, 2005 p 623). The resulting number is the number of accumulated degree-days needed for the specimen to reach the state of decomposition observed by the total body score assigned to the individual. To calculate the date of death, daily averages need to be calculated from the nearest weather station, for our project, we use the Hobo Pro Series data logger and the data from the Greenough Hill weather station. Working backwards from the date of discovery, the daily averages are added together until the accumulated sum from the equation is reached. Daily averages totaling 0°C and below are given an accumulated degree value of zero. The date of death is the day the accumulated sum of the equation is reached.
Chapter 4: RESULTS

The results presented are a compilation of visual observations obtained from visits to the research site and weather data recorded from the Hobo Pro Series data logger and the Road Weather Information System (NWRS) weather station located at Greenough Hill. Visual observations serve to describe the state of decomposition, calculate a total body score, and examine insect succession of both specimens. Temperature data recorded from the Hobo data logger and the NWRS weather station was independently used to calculate the time of death for each specimen.

Stages of Decomposition

The stages associated with decomposition outlined in the previous chapter assist in the understanding of the decay rates of the two specimens.

Specimen #1: Fresh Stage

SS-1 was put down and deposited at the research site on August 6, 2008 (Figure 5). The fresh stage of decomposition began on this date (day 1) and continued until day 2 when the carcass began to bloat. The weather conditions on the day of placement were hot and dry with an ambient temperature of 35°C with 12% relative humidity. Flies were attracted to the carcass immediately upon deposition and other insects present included blowflies, hornets, butterflies, and a species of dragonfly.

Specimen #1: Early Decomposition

Day 2, August 7, 2008 marked the end of the fresh stage and the beginning of the early decomposition stage, which lasted until day 6, August 11, 2008. This stage is
characterized by discoloration of the body, bloating and purging of decompositional fluids, and a period of post bloating after the release of abdominal gasses. On day 2, the carcass was fully bloated with decompositional fluids purging from the mouth, nose, and anus and entrails pushed from the anus (Figure 6). The skin was pink and marbled, but fresh in appearance and the pooling of blood inside the body, lividity, had begun. Flies were prevalent especially around the mouth, nose, and anal regions. There was no visible sign of fly eggs or fly larvae but flying insects (Diptera), especially from the family Calliphoridae such as *Phormia regina* and *Lucidia illustrus*, referred to as blow flies, are prominent. Odor associated with this stage was mild and characteristic of the natural scent of the animal and fecal materials.

By day 4, the carcass began to deflate and entered an active state of decomposition (Figure 7). The skin was pale in color with areas of green to gray discoloration on the ventral aspect of the abdomen. Skin was brown and beginning to exhibit signs of drying on the head, legs and ventral aspect of the abdomen where the carcass was in contact with the ground. Volatile fatty acids started to leach from the body and form a dark black stain all the way around the carcass.

Maggot activity began and was extensive, concentrating on the open orifices of the eyes, ears, nose, mouth and anus. Other regions that exhibited extensive maggot activity included the neck, back of the head where the gunshot wound was located, and stomach region. Maggots appeared to be in the first instar larvae stage.

August 10, 2008 (day 5) through August 11, 2008 (day 6) showed an increase in maggot activity as they had spread to all other regions of the body, especially
concentrated in open orifices and where the body was in contact with the ground surface (Figure 8, Figure 9). The size of the maggots increased as they continued to feed. 

*Lucidia illustrus* is the primary Dipterian insect and the Histerdae (hister beetles) from the family Coleoptera, have arrived. The hair and skin on the dorsal aspect of the trunk began to peel and slough off. The black stain resulting from the leaching of the volatile fatty acids increased in size to approximately 30 cm surrounding the entire carcass. Odor from the carcass was severe and pungent and could be detected over 50 yards away.

Figure 5: SS-1, Day 1, August 6, 2008
Figure 6: SS-1, Day 2, August 7, 2008

Figure 7: SS-1, Day 4, August 9, 2008
Figure 8: SS-1, Day 5, August 10, 2008

Figure 9: SS-1, Day 6, August 11, 2008
Specimen #1: Advanced Decomposition

Advanced decomposition began on day 7, August 12, 2008 (Figure 10) and lasted until skeletonization. This stage is characterized by the sagging of flesh and the caving in of the abdominal cavity. In dry environments, mummification of the skin will occur. On Day 7, the abdominal cavity caved in and the skin began to sag. Skin of the head, neck, chest, and shoulder regions continued to peel and flake off. The carcass continued to darken and dry out especially on the head, neck, legs, ventral aspect of the abdomen and dorsal aspect of the trunk. The most notable areas of drying included the ears, mouth, nose, and eyes. The maggot activity began to change, as the masses appeared to slightly reduce in size and may have moved inside the carcass. On this day, immature Staphylinidae beetles and an abundance of Histerdae beetles are present and stay with the carcass until day 18, August 23, 2008. The Dipterian insects included many Piophilidae (cheese-skippers). The number of Piophilidae increased through day 18.

By day 9, August 14, 2008, the maggots were visible only around the edge of the carcass because they had begun to move inside the carcass (Figure 11). The maggots crowded inside the abdominal cavity and were stacked up on each other in an effort to gain access to the body. This was observed by looking into the opening of the abdominal cavity made by the feeding maggots at the point where the carcass made contact with the ground (Figure 12). The skin is hard and dry with a leathery texture providing protection for the maggots from the sun but the stomach remains soft with decompositional fluids. The odor is still very apparent and can be detected over 25 yards away. By day 10, August 14, 2008, the maggots were no longer visible as they migrated completely inside
the abdominal cavity (Figure 13).

From day 11, August 16, 2008 to day 123, December 7, 2008, (Figure14) the carcass exhibited a lapse in major changes and was characterized by the drying of the skin, the sloughing of the skin and hair, and declining odor. On day 13, August 18, 2008, the maggots were observed moving away from the carcass to burrow into the soil to pupate. This activity was not observed to occur in maggot masses but individually. The odor associated with the carcass during this time was putrid but declining in severity. Skin discoloration includes areas of cream, light brown, medium brown, dark brown, black, red, and orange tones. On day 15, August 21, 2008 small amounts of adipocere appeared on the head and hindquarter following a day of steady rainfall.

Insect succession is the only major activity that occurred with the carcass during this stage of decay and clear patterns of succession were observed. On Day 17, August 23, 2008 Dipterian insects are prominent and a large number of recently emerged *Phormia regina* were observed. On day 18, August 24, 2008, Piophilidae larvae (cheese-skippers) arrived on the carcass and are distinguished by their jumping and skipping behavior they exhibit when disturbed or threatened. In addition, on this day, another recently emerged group of *Phormia regina* are present. A third wave of recently emerged *Phormia regina* are discovered from day 26, September 1, 2008 through day 32, September 7, 2008. On day 34, September 9, 2008, a large number of unidentifed, but recently emerged, Dipterian Calliphoridae have appeared and on day 46, September 21, 2008, a large group of recently emerged *Phormia regina* arrive. Nitidulidae (sap beetles) arrive on day 53, September 2008. Immature Dermestidae beetles appear on day 63, October 8, 2008 and on day 89 immature Staphylinidae appear. Also abundant on day 89
are Piophilidae.

On day 250, April 12, 2009, the carcass exhibited very few changes compared to day 123 (Figure 15). The carcass was dry to the touch and hollowed out on the inside with the exception of a small golf ball sized amount of soft stomach contents. A small group of small maggots were on top of this substance. The odor from the carcass was barely detectible and had a musty smell.

Figure 10: SS-1, Day 7, August 12, 2008
Figure 11: SS-1, Day 9, August 14, 2008

Figure 12: SS-1, Day 9, August 14, 2008, Maggot activity on the ventral aspect of the abdomen
Figure 13: SS-1, Day 10, August 15, 2008

Figure 14: SS-1, Day 110, November 23, 2008
Specimen #2: Fresh Stage

SS-2 was put down and deposited at the site on October 13, 2008 (Figure 16). The fresh stage of decomposition began on this date (day 1), day one, and continued until the last observation prior to snowfall on day 55, December 7, 2008. The weather conditions on the day of placement were cool and dry with an ambient temperature of 8°C with 60% relative humidity. On day one, October 13, 2008, the skin was pink and the carcass exhibited an odor natural to the scent of animal and fecal materials. A blowfly and a spider arrived on the carcass shortly after placement.

Very few changes occurred to the carcass from day 2, October 14, 2008 through day 55, December 7, 2008. On day 2, the skin around the abdomen darkened to a pink,
the abdomen was firm to the touch and excrement protruded from the anus (Figure 17). The desiccation of the tongue and the darkening of the skin of the abdomen from pink to purple were the only observable changes that occurred prior to snowfall (Figure 18).

Figure 16: SS-2, Day 1, October 13, 2008
Figure 17: SS-1, Day 2, October 14, 2008

Figure 18: SS-2, Day 8, October 20, 2008
Patterns of insect succession were observed but due to colder temperatures, the occurrence of insects visiting the carcass was decreased in comparison to the first specimen. Dipterian insects observed were Scathophagidae and Phroidae. No Calliphoridae were observed. Scathophagidae arrive on day 5, October 17, 2008 and stay through day 55, December 7, 2008, the last day of observation prior to snowfall. Coleopterian beetles observed were of the Family Cleridae (clerid beetles) and Staphylinidae (rove beetles). Cleridae arrived on day 12, October 24, 2008 and were found in small numbers through Day 55. Staphylinidae arrived on day 5, October 17, 2008 and were also found in small numbers through Day 55.

**Specimen #2: Early Decomposition**

On day 180, the first observation after snowmelt, the carcass was in the early decomposition stage showing signs of decomposition (Figure 19). The carcass was slightly bloated and the purging of fluids from the vaginal region and mouth had begun. The odor associated with the carcass, although faint, was characteristic of the pungent smell of decomposition. The skin was gray in appearance but darkened to a purple and dark red on the abdomen and on the legs. The skin was particularly dried out on the ventral aspect of the abdomen and was bubbled in appearance. Portions of the skin on the ventral aspect of the abdomen were splitting in some locations and there are patches of white skin along the abdomen and hind legs. Insect activity is high and several blowflies were on and around the carcass. No maggot activity was visible.
Many differences can be seen in the rate of decay between the two test specimens. Specimen #1 exhibited a rapid rate of decay compared to specimen #2 because specimen #1 was placed in August when temperatures were very high and the humidity was very low. Specimen #2 was placed in October when temperatures were cool and humidity was low. The lower temperatures and the lack of insect activity slowed the process of decay for the second specimen so much that it remained in the fresh stage of decomposition for the 3 months prior to snowfall. Specimen #1 entered the early decomposition stage and began to bloat on the second day of placement whereas; specimen #2 did not enter the early decomposition stage until the snow melted in April.
Accumulated Degree Days

Specimen #1

SS-1 was given a total body score (TBS) for four dates chosen through a random number generator from day one to day 250. The dates were 8/12/08 (day 7), 9/9/08 (day 36), 10/8/08 (day 65), and 10/26/08 (day 83). Additionally SS-1 was scored the final day of observation on 4/12/09 (day 250). The point values for the scoring process can be seen in the tables below:

Table 4: 8/12/08 (day 7)

<table>
<thead>
<tr>
<th>Region</th>
<th>Stage</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Advanced</td>
<td>7</td>
<td>Caving in of the flesh and tissues of the eyes and throat</td>
</tr>
<tr>
<td>Trunk</td>
<td>Advanced</td>
<td>6</td>
<td>Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity.</td>
</tr>
<tr>
<td>Limbs</td>
<td>Advanced</td>
<td>7</td>
<td>Mummification with bone exposure of less than one half that of the area being scored.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>

Table 5: 9/9/08 (day 36)

<table>
<thead>
<tr>
<th>Region</th>
<th>Stage</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Advanced</td>
<td>9</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Trunk</td>
<td>Advanced</td>
<td>7</td>
<td>Moist decomposition with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Limbs</td>
<td>Advanced</td>
<td>7</td>
<td>Mummification with bone exposure of less than one half that of the area being scored.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>
### Table 6: 10/8/08 (day 65)

<table>
<thead>
<tr>
<th>Region</th>
<th>Stage</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Advanced</td>
<td>9</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Trunk</td>
<td>Advanced</td>
<td>8</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Limbs</td>
<td>Advanced</td>
<td>7</td>
<td>Mummification with bone exposure of less than one half that of the area being scored</td>
</tr>
</tbody>
</table>

### Table 7: 10/26/08 (day 83)

<table>
<thead>
<tr>
<th>Region</th>
<th>Stage</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Advanced</td>
<td>9</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Trunk</td>
<td>Advanced</td>
<td>8</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Limbs</td>
<td>Advanced</td>
<td>7</td>
<td>Mummification with bone exposure of less than one half that of the area being scored</td>
</tr>
</tbody>
</table>

### Table 8: 4/12/09 (day 250)

<table>
<thead>
<tr>
<th>Region</th>
<th>Stage</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Advanced</td>
<td>9</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Trunk</td>
<td>Advanced</td>
<td>8</td>
<td>Mummification with bone exposure less than one half that of the area being scored</td>
</tr>
<tr>
<td>Limbs</td>
<td>Advanced</td>
<td>7</td>
<td>Mummification with bone exposure of less than one half that of the area being scored</td>
</tr>
</tbody>
</table>

24
Each TBS was employed with the ADD formula to estimate the date of death based on daily temperature averages generated from the Hobo Pro Series data logger and the NRWS weather station.

**Table 9: 8/12/08 (day 7), TBS = 20**

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated ADD</td>
<td>407</td>
<td>407</td>
</tr>
<tr>
<td>Calculated ADD range (80% confidence interval)</td>
<td>19.2-795.5</td>
<td>19.2-795.5</td>
</tr>
<tr>
<td>Estimated date of death</td>
<td>7/22/08-7/23/08</td>
<td>7/20/08-7/21/08</td>
</tr>
<tr>
<td>ADD to actual date of death</td>
<td>150 (8/6/08)</td>
<td>128 (8/6/08)</td>
</tr>
</tbody>
</table>

**Table 10: 9/9/08 (day 36), TBS = 23**

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated ADD</td>
<td>737</td>
<td>737</td>
</tr>
<tr>
<td>Calculated ADD Range (80% confidence interval)</td>
<td>349-1125</td>
<td>349-1125</td>
</tr>
<tr>
<td>Estimated date of death</td>
<td>7/26/08-7/27/08</td>
<td>7/22/08-7/23/08</td>
</tr>
<tr>
<td>ADD to actual date of death</td>
<td>540 (8/6/08)</td>
<td>493 (8/6/08)</td>
</tr>
</tbody>
</table>
Table 11: 10/8/08 (day 65), TBS = 24

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calculated ADD</strong></td>
<td>916</td>
<td>916</td>
</tr>
<tr>
<td><strong>Calculated ADD range (80% confidence interval)</strong></td>
<td>527-1304</td>
<td>527-1304</td>
</tr>
<tr>
<td><strong>Estimated date of death</strong></td>
<td>8/1/08-8/2/08</td>
<td>7/24/08-7/25/08</td>
</tr>
<tr>
<td><strong>ADD to actual date of death</strong></td>
<td>832 (8/6/08)</td>
<td>711 (8/6/08)</td>
</tr>
</tbody>
</table>

Table 12: 10/26/08 (day 83), TBS = 24

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calculated ADD</strong></td>
<td>916</td>
<td>916</td>
</tr>
<tr>
<td><strong>Calculated ADD range (80% confidence interval)</strong></td>
<td>527-1304</td>
<td>527-1304</td>
</tr>
<tr>
<td><strong>Estimated date of death</strong></td>
<td>8/4/08</td>
<td>7/29/08-7/30/08</td>
</tr>
<tr>
<td><strong>ADD to actual date of death</strong></td>
<td>884 (8/6/08)</td>
<td>792 (8/6/08)</td>
</tr>
</tbody>
</table>
Table 13: 4/12/09 (day 250), TBS = 24

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated ADD</td>
<td>916</td>
<td>916</td>
</tr>
<tr>
<td>Calculated ADD range (80% confidence interval)</td>
<td>527-1304</td>
<td>527-1304</td>
</tr>
<tr>
<td>Estimated date of death</td>
<td>8/7/08-8/8/08</td>
<td>8/4/08-8/5/08</td>
</tr>
<tr>
<td>ADD to actual date of death</td>
<td>984 (8/6/08)</td>
<td>897 (8/6/08)</td>
</tr>
</tbody>
</table>

The results of the analysis show the efficiency of the ADD method for SS-1 for multiple estimations including the most accurate estimation of date of death following the winter period. The estimated dates for the Hobo data logger and the NRWS weather station are consistent with little variation. The date of death for SS-1 was August 6, 2008. The scoring and calculations for August 12, 2008 (day 7) estimate a date of death between July 22, 2008 and July 23, 2008 for the hobo data logger, which is 15-16 calendar days prior to the actual death and between July 20, 2008 and July 21, 2008 for the weather station, which is 17-18 calendar days prior to the actual death. The number of ADD required to reach the actual date of death is 150 with the hobo data logger and 128 with the weather station. These results show that the date of death falls within the 80% confidence interval range for both data sources.

The scoring calculations for September 9, 2008 (day 36) estimated a date of death between July 26, 2008 and July 27, 2008 using the Hobo data logger, which is 12-13 calendar days prior to actual death. The weather station data indicated a date of death between July 22, 2008 and July 23, 2008, which is 15-16 calendar days prior to death.
Using the data logger, the number of ADD required to reach the actual date of death is 540. Using the weather station, the number of ADD required to reach the actual date of death is 493. These results show that the date of death falls within the 80% confidence interval range for both data sources.

The scoring and calculations for October 8, 2008 (day 65) estimated a date of death between August 1, 2008 and August 2, 2008 using the hobo data logger, which is 5-6 calendar days prior to actual death. The weather station data indicated a date of death between July 24, 2008 and July 25, 2008, which is 13-14 calendar days prior to death. Using the data logger, the number of ADD required to reach the actual date of death is 832. Using the weather station, the number of ADD required to reach the actual date of death is 711. These results show that the date of death falls within the 80% confidence interval range for both data sources.

The scoring calculations for October 26, 2008 (day 83) estimated a date of death on August 4, 2008 using the hobo data logger, which is only 2 calendar days prior to the actual date of death. The weather station data indicated a date of death between July 29, 2008 and July 30, 2008, which is 7-8 calendar days prior to the actual date of death. Using the data logger, the ADD required to reach the actual date of death is 884. Using the weather station, the number of ADD required to reach the actual date of death is 792. These results show that the date of death falls within the 80% confidence interval range for both data sources.

The scoring calculations for April 12, 2008 (day 250) indicated a date of death between August 7, 2008 and August 8, 2008 using the data logger, which is only 1-2
calendar days after the actual date of death. The weather station data indicated a date of
death between August 4, 2008 and August 5, 2008, which is only 1-2 days prior to the
date of death. Using the data logger, the number of ADD required to reach the actual
date of death is 984. Using the weather station, the number of ADD required to reach the
actual date of death is 897. These results show that the date of death falls within the 80%
confidence interval range for both data sources.

Specimen #2

SS-2 was given a total body score for two dates chosen through a random number
generator from day one to day 181. The dates were 10/20/08 (day 8) and 12/7/08 (day
56). Additionally SS-2 was scored the final day of observation on 4/12/09 (day 181).
The point values for the scoring process can be seen in the tables below:

Table 14: 10/20/08 (day 8)

<table>
<thead>
<tr>
<th>Region</th>
<th>Stage</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>Early decomp</td>
<td>2</td>
<td>Pink-white appearance with skin slippage and some hair loss</td>
</tr>
<tr>
<td>Trunk</td>
<td>Fresh</td>
<td>1</td>
<td>Fresh, no discoloration</td>
</tr>
<tr>
<td>Limbs</td>
<td>Fresh</td>
<td>1</td>
<td>Fresh, no discoloration</td>
</tr>
</tbody>
</table>

4
Each TBS was used in conjunction with the ADD formula, and the estimated date of death based on the ADD calculated was determined by using daily temperature averages generated from the Hobo Pro Series data logger and the NWRS weather station.
Table 17: 10/20/08 (day 8), TBS = 4

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated ADD</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Calculated ADD range (80% confidence interval)</td>
<td>-318-458</td>
<td>-318-458</td>
</tr>
<tr>
<td>Estimated date of death</td>
<td>10/4/08</td>
<td>10/7/08</td>
</tr>
<tr>
<td>ADD to actual date of death</td>
<td>41 (10/13/08)</td>
<td>33 (10/13/08)</td>
</tr>
</tbody>
</table>

Table 18: 12/7/08 (day 56), TBS = 4

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated ADD</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td>Calculated ADD range (80% confidence interval)</td>
<td>-302-474</td>
<td>-302-474</td>
</tr>
<tr>
<td>Estimated date of death</td>
<td>10/24/08</td>
<td>10/14/08-10/15/08</td>
</tr>
<tr>
<td>ADD to actual date of death</td>
<td>127 (10/13/08)</td>
<td>98 (10/13/08)</td>
</tr>
</tbody>
</table>

Table 19: 4/12/09 (day 181), TBS = 13

<table>
<thead>
<tr>
<th></th>
<th>Hobo Data Logger</th>
<th>Weather Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated ADD</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Calculated ADD range (80% confidence interval)</td>
<td>-188-528</td>
<td>-188-528</td>
</tr>
<tr>
<td>Estimated date of death</td>
<td>10/17/08</td>
<td>10/15/08-10/16/08</td>
</tr>
<tr>
<td>ADD to actual date of death</td>
<td>156 (10/13/08)</td>
<td>156 (10/13/08)</td>
</tr>
</tbody>
</table>
The negative values shown in the 80% confidence interval range indicate a problem with the ADD formula. The calculated ADD range represents a range of accumulated degree-days that the scored individual will fall into with 80% confidence. A negative ADD is not possible due to the fact that there are no negative accumulated degree-days; the smallest amount of degree-days possible is zero. If an individual has a low body score, then the 80% confidence interval will include negative degree-days. This portion of the formula needs revision.

The results of the analysis show the accuracy of the ADD method for SS-2 for multiple estimations including the estimation of date of death following the winter period. The scoring and calculations for October 20, 2008 (day 8) indicate a date of death of October 4, 2008 using the Hobo data logger, which is 10 calendar days prior to the actual date of death. The weather station data indicated a date of death being October 7, 2008, which is 6 calendar days prior to the actual date of death. Using the data logger, the number of ADD required to reach the actual date of death, October 13, 2008, is 41. Using the weather station, the number of ADD required to reach the October 13, 2008 date of death is 33. These results show that the date of death falls within the 80% confidence interval range for both data sources.

The scoring and calculations for December 7, 2008 (day 56) estimate a date of death of October 24, 2008 using the hobo data logger, which is 11 calendar days after the actual date of death. The weather station date indicated a date of death being between October 14, 2008 and October 15, 2008, which is 1-2 days after the actual date of death. Using the data logger, the actual number of ADD required to reach the actual date of death is 127. Using the weather station, the actual number of ADD required to reach the
date of death is 99. These results show that the date of death falls within the 80% confidence interval range for both data sources.

The scoring and calculations for April 12, 2009 (day 181) estimate a date of death of October 17, 2008 using the data logger, which is four calendar days after the actual date of death. The weather station data indicate a date of death between October 15, 2008 and October 16, 2008, which is 2-3 calendar days after death. Using the data logger, the actual number of ADD required to reach the actual date of death is 156. Using the weather station, the actual number of ADD is 156. These results show that the date of death falls within the 80% confidence interval range for both data sources.
Chapter 5: DISCUSSION

The purpose of this research is to document the process of decomposition for two *Sus scrofa* carcasses in west central Montana. A greater understanding of decomposition in this unique climate will enable better estimates of the postmortem interval of the region.

Two hypotheses are proposed for this study. Hypothesis 1: Decay rates of areas exhibiting cooler ambient temperatures and low humidity, such as west central Montana, will be slower than decay rates of areas characterized by hot and humid temperatures, such as Tennessee. Hypothesis 2: The use of accumulated degree-days (ADD) to predict the date of death will calculate incorrect dates of death when applied to individuals in climatic areas such as west central Montana due to prolonged periods of stasis caused by long winters and heavy snowfall.

It is clear from the results of this study that the rate of decomposition in west central Montana is slower than the rate of decomposition in areas that exhibit hot and humid climatic conditions. It is also clear from this study that the decomposition rate of the summer carcass (SS-1) is faster than the decomposition rate of the autumn carcass (SS-2). The low humidity, allowed for the mummification of the SS-1 carcass resulting in the incomplete decay. The cool temperatures of the autumn slowed the biological process of decay for the SS-2 carcass and prevented substantial insect activity. This allowed the carcass to enter a period of stasis in the fresh stage of decomposition prior to the winter. These results support the first hypothesis and we cannot reject it.

Figure 20 illustrates the duration in days that each specimen remained in each
stage of decay and shows the major differences that temperature has on the rate of decay. The fresh and early stages of decay for specimen #1 occurred for 1 and 6 days, respectively. The fresh stage for specimen #2 lasted for a period of 180 days. Specimen #1 remained in the advanced stage of decay for 244 days while specimen #2 never reached the advanced stage of decay despite 181 days of exposure. The results show how summer temperatures quicken the rate of decay and how cooler autumn temperatures slow the rate of decay.

Figure 20: Duration of stages of decomposition for each specimen

Data collected from this study differs significantly than data collected from previous studies such as Payne (1965). Payne’s study of baby Sus scrofa specimens
occurred in the summers of 1962 and 1963 in South Carolina, an environment characterized by hot temperatures and humid air. His study found rapid rates of decay with the carcasses entering the remains stage after 4 weeks. His findings were a result of high ambient temperatures and high relative humidity. Mann et al (1990) found, over a period of 8 years of decomposition research in Tennessee, that in warm to hot weather conditions, nearly complete skeletonization to complete skeletonization of human bodies can occur in as little as two to four weeks. This study, however, shows that 8 months have passed for specimen number 1 without the occurrence of skeletonization. The process of mummification was observed by Galloway et al. (1989) in the hot and dry environment of Arizona and was similar to the effects of the hot and dry temperatures exhibited by this summer study. Bunch (2009) observed skeletonization of a sample placed in the cold and moist climate of upstate New York after one year. This skeletonization occurred after a period of winter with snow cover. The other two samples in her study did not completely skeletonize but did exhibit partial skeletonization. The skeletonization of her specimens after the winter period may be explained by the higher levels of year-round relative humidity that are not characteristic of year-round levels in Montana.

One major goal of this study was to test the estimation of the postmortem interval by using a model of accumulated degree-days derived from Megyesi (2005). Megyesi used 68 cases to test the ADD model and estimate the postmortem interval from accumulated degree-days rather than calendar days. Most of the cases tested were from areas of the Midwest United States with one case, case #53, from Missoula, MT. Megyesi (2005) excluded case #53 from the results section because, “case #53 is most
likely an outlier due to other environmental factors specific to Montana that were not
directly controlled for in this study such as altitude or rainfall” (p. 626).

The wintering of the carcasses had a significant impact on the decomposition of
the test specimens. The carcasses were covered in undisturbed snow for a period of three
months where they were insulated from the harsh ambient temperatures by the subnivian
space created by the air pockets in the snow. We know this to be true because the Hobo
Pro Series data logger placed on the ground with the carcasses (under snow) recorded
warmer temperatures than the Greenough Hill weather station, which recorded much
cooler ambient temperatures. Figure 21 shows the data logger temperatures as well as
recorded humidity for the duration of this study.

![Figure 21: Temperature and relative humidity 8/7/08-4/12/09](image)
The subnivian space is described as a thin air layer found between the covering snow and the surface of the soil and its vegetative debris. This space forms especially well when the snowfall becomes established prior to the hard freezing of the soil. A winter with a continuous snow cover will allow a significant and continuous subnivian space to form. The micro-climatic conditions of the subnivia are sufficiently mild to allow temperature sensitive invertebrates (beetles, collembola, mites and spiders) to continue their ecological activities of decomposition and predation throughout the winter season.

Although the temperature readings were higher under the snow, they were still below freezing allowing for the biological process of decay to slow. The temperatures recorded from the data logger and the weather station varied, the most important finding was that the accumulated degree-day calculations for each were consistent with one another. This finding supports the use of a nearby weather station data by law enforcement officers and death investigators when trying to determine the PMI for a deceased individual.

Figures 22 and 23 show the comparisons of the ADD calculations with the Hobo data logger and weather station information for specimens’ number 1 and 2 respectively.

This chart (Figure 22) shows the comparisons of ADD calculations for specimen number 1. The expected number of ADD generated from the regression formula provided by Megyesi (2005) and the observed values generated from data provided by the data logger on the ground surface as well as the Greenough Hill weather station are represented. The close relationship between the observed data logger and observed
weather station data illustrates the accuracy of the ADD model with the actual date of death, even through long periods of stasis, such as the winter season.

The next chart (Figure 23) shows the comparisons of ADD calculations for specimen number 2. The expected number of ADD generated from the regression formula provided by Megyesi (2005) and the observed values generated from data provided by the data logger on the ground surface as well as the Greenough Hill weather station are represented. The close relationship between the observed data logger and observed weather station data illustrates the accuracy of the ADD model, even through
long periods of stasis, such as the winter season.

**Figure 23: SS-2 ADD Comparisons**

When the ADD model was applied to the two test specimens in this study, the ADD method produced PMI estimations two weeks prior to the actual dates of death for the carcasses during the earlier stages of decomposition. The ADD model became more accurate as decay progressed producing PMI estimations within days of the actual dates of death. Interestingly, the PMI estimations for both carcasses on the April 12, 2009 test date after the winter season were the most accurate, placing the date of death only 1-3 days from the actual date of death in each circumstance. The results show that although
the PMI estimations fall within the 80% confidence interval allowed by the formula, there is a pattern to the error rate in the ADD estimations. The pattern indicates that the ADD estimations are less accurate for the earlier stages of decay and more accurate in the later stages of decay. This is explained by the fact that decomposition is slowed by cooler temperatures and lower humidity confounded with the continued accumulation of degree-days as time progresses. When decomposition slows and degrees accumulate, the accuracy of the ADD model is shown.

Although the accuracy of the ADD model converges in the later stages of decay the null hypothesis that the ADD method works for climates characterized by cold temperatures and low humidity cannot be completely rejected. However, the alternative hypothesis that states that low temperatures and low humidity will impact the accuracy of the ADD method due to prolonged periods of stasis due to long winters and heavy snowfall must be rejected as the ADD model was most accurate after the winter and spring thaw. This study supports the conclusions by Megyesi (2005) that decomposition is more accurately modeled as dependent on accumulated temperature rather than time.

It must be noted that the continued accuracy of the ADD model is yet to be determined. The state of mummification shown by SS-1 is not likely to change to the skeletonization phase of decomposition for many months, perhaps years. As a result, the TBS will not change enough to produce ADD estimations that differ from the current estimations, however, degree days will continue to accumulate.

Although accuracy of the ADD model is reported in this study, the use of ADD to calculate the PMI must be used with caution. The scoring method is broad and
ambiguous, which requires the observer to make a “best guess” when placing an individual into category descriptions. Individuals may exhibit characteristics of one category but also exhibit characteristics in another category. This confounds the process and leads to the possibility of interobserver error when scoring the carcasses. The ADD model proposed by Megyesi (2005) and used in this study accounts for an 80% confidence interval. This interval reflected a standard error of +/- 388.16 days, which is a large standard error especially when dealing with cold temperatures. A standard error of 388.16 ADD in cold temperatures could allow PMI estimations to be accepted despite the possibility that they are off by many weeks and even months. This could impact the investigation of the identity of a deceased individual, the identification of a suspect and/or impact the timeline associated with the deceased individuals death or disappearance. An additional problem with the standard error occurs when ADD estimations are small and the 80% confidence interval results in a negative ADD range. A range cannot have a negative number and must start at zero ADD.

The warmer environment may have an effect on the entomology, as it may be warm enough to sustain maggot activity and allow them to survive the winter as seen from Wagster (2007). Wagster reported that larvae, such as Piophilidae are able to survive cold weather by generating heat when congregating together. This is how the over-wintering of larvae prevails. If this is true, then there are decomposition processes occurring on the inside of the carcass that we were not equipped to deal with in this study.

Insect succession analysis of sample number 1 is consistent with the insect succession patterns observed by Barnes (2003). Barnes reported a high frequency of
Phormia regina in his control (unburned) specimen in the fresh stage of decomposition and the appearance of Lucidia illustrus in the early and advanced stages of decomposition. Barnes also noted the appearance of Piophilidae in the advanced decay stage, however, he noted very few in comparison to those observed in this study. Species of Coleoptera were also consistent with Barnes assessment showing a high frequency of Histerdae. One major difference in the Coleoptera samples is the number of Staphylinidae collected in this study as compared to Barnes (2003). This study shows an abundance of Staphylinidae for SS-1, whereas Barnes reports very few. Overall, it must be noted that this study included a higher abundance of all insects in comparison to the numbers collected by Barnes. This could be due to the differences in the methods of insect collection. Barnes (2003) conducted a summer study on insect succession patterns, therefore, comparisons of specimen’s #1 and #2 insect succession in autumn, winter, and spring could not be compared.
Chapter 6: CONCLUSION

The results presented in this study are the first of a series of systematic decomposition studies at the Lubrecht Experimental Forest. This study, although preliminary and reflects a controlled test environment, provides valuable, never before tested information about the decomposition process in west central Montana. Data collection for a study such as this one is extremely important to understanding the complex process of decomposition. Temperature and humidity are related to all aspects of decomposition and influence the succession of insects and their behaviors when visiting carrion.

This study adds an unknown component to the research available on decomposition studies and shows that although variable, temperature is the number one factor in the rate of decay in deceased individuals. This research also shows the significant effect temperature plays in PMI estimations. The results of this study showed that hot and dry summer temperatures allowed for the rapid rate of decomposition and abundance of insect activity for specimen #1. In contrast, specimen #2 exhibited a much slower rate of decay and low insect activity in the cooler autumn months. Although hot and dry temperatures allowed for the rapid decomposition of specimen #1, the rate of decomposition for both carcasses in west central Montana is slower than the rate demonstrated in east Tennessee, Arizona, British Columbia, and upstate New York.

The accuracy demonstrated in the results from the ADD estimations is important to employing the use of the ADD model for our unique climate region. The ADD estimations made from the total body scoring method and the results of the ADD model
itself can have a profound impact on the way the PMI estimations are assessed. It will be important for future researchers to employ the ADD model and continue to test the accuracy of the method at different stages of decomposition, including skeletonization.

Although extensive and detailed, the materials and methods employed in this study are repeatable and future studies are encouraged. A project of this magnitude demands further exploration in order to establish the accuracy rate of the estimation of the PMI. A larger sample size and information from all seasons of the year would be valuable in order to build a database of decomposition and insect succession information. Additionally, studies of differential deposition, varied wrappings, buried, and burned carcasses can be explored. The continued analysis and calculation of ADD would strengthen the justification for the continued use of the method or the justification for the discontinuation of the method in light of new ways to estimate the PMI.
REFERENCES CITED


Appendix A: Bear Management Plan for Decomposition study, Lubrecht Forest

SITE

Site location is above and out of site from a dirt road accessed from Highway 200. The access road is gated and locked at the highway to prohibit public vehicular access at all times.

SIGNAGE

Signs prohibiting public access will be placed around the site perimeter approximately 100 yards around the site. The signs will read: “Sensitive Research Area – Please Do Not Enter. For information please contact Dr. Ashley McKeown, University of Montana, 243-2145”. Next to the containment area signs will read: “High Voltage Electrified Fencing. Please stay back”.

PATROL/MONITORING

The area around the site will be patrolled at each site visit and closely monitored for any sign of bear activity (scat, scavenging, tracks).

CONTACT WITH BEAR SPECIALIST

For the entire duration of the project, Carleen Gonder* will remain in frequent contact with James Jonkel, Montana Fish, Wildlife and Parks (FWP) area bear management specialist/biologist, who will notify her if there have been any bear sightings in the greater area (from Clearwater Junction to Potomac Valley). They will have ability to contact one another or designated assistants at all times. Gonder will contact Hillary Parsons (primary researcher) with any bear sightings.

SEASONAL CONSIDERATIONS

Seasonal movements of grizzlies will be taken into consideration. During spring and fall periods the bears are most hyperphagic, and could potentially move through the Lubrecht area.

BEAR ACTIVITY OR SIGN OBSERVED

If any sign of bear activity is observed, or if there is a sighting of a grizzly bear or black bear, Carleen Gonder will be notified and she will contact J. Jonkel with a description of all activity. Any additional instructions from him will be written in a log and followed.

BEAR/HUMAN INCIDENT

If there is a bear/human incident, J. Jonkel, and Dr. Chris Servheen, US Fish and Wildlife Service National Grizzly Bear Coordinator will be immediately notified and protocols per the Endangered Species Act will be followed. Additionally, Dr. Dan Doyle will be notified as the UM public relations contact.
LUBRECHT PERSONNEL OBSERVING BEAR ACTIVITY OR SIGN

All Lubrecht personnel will be instructed to immediately contact C. Gonder if any bear activity is observed. She will then investigate and take appropriate action as stated above and contact Hillary Parsons. If C. Gonder is out of the area, J. Jonkel or his assistant will be immediately notified.

A contact sequence is attached to this Plan.

* C. Gonder has been a commissioned law enforcement officer for wildlife and land management government agencies for 5 years. While she does not have law enforcement authority during this project, she will rely on her training to be an astute observer with sound judgment in noting and documenting unusual activity, and notifying area law enforcement personnel. She also was a full time bear management specialist in Glacier National Park for 2 seasons and is highly trained in recognizing potential bear/human conflict concerns and mitigating issues in both front and back country settings.

ORDER OF CONTACT

1. Lubrecht employees observe bear or bear sign (grizzly or black bear) in the greater Lubrecht area
   A. Contact C. Gonder immediately. If she is out of the area…
   B. Contact J. Jonkel. If no response…
   C. Contact B. Wiesner.
   AND contact Frank Maus

2. Bear/human conflict; no injury
   *Detain individuals for interview by C. Gonder and J. Jonkel or other FWP personnel*
   A. Contact C. Gonder immediately. If no response…
   B. Contact J. Jonkel. If no response…
   C. Contact B. Wiesner. If no response…
   D. Contact Capt. Darrah
   AND contact Frank Maus AND Dr. Dan Doyle if unable to contact C. Gonder

3. Bear/human conflict; injury
   A. Call 911
   B. Then contact J. Jonkel. If no response…
   C. Contact B. Wiesner. If no response…
   D. Contact Capt. Darrah
   AND contact Frank Maus AND C. Gonder. If unable to contact C. Gonder, contact Dr. Doyle.
CONTACTS

Carleen Gonder
  Home – 244-0007
  Cell – (I will be getting a cell phone for the duration of the project)

James (Jamie) Jonkel – Area FWP bear management specialist
  FWP/office – 542-5508
  Cell – 544-1447
  Home – 728-3275

Bob Wiesner – Assistant bear management specialist
  Cell – 240-3296
  Home – 543-6358

Game Wardens

Captain Jeff Darrah – Missoula Region warden Captain
  FWP/office – 542-5512
  Cell – 240-0982
  Home – 777-4257

Sgt. Dan Curtin – Missoula
  Cell – 240-0932
  Home – 273-0868

Derek Schott – Missoula
  Cell – 240-2579
  Home – 273-7968

Bill Koppen – Seeley Lake
  Cell – 210-1299
  Home – 677-3628

Frank Maus – Lubrecht Manager
244-5524, ext. 1

Dan Doyle, PhD. – Committee chair and public relations contact
243-5912

Hillary Parsons – Masters student and primary researcher
580-5881
Appendix B: Carcass Descriptions and Observations

Observer ___________________________ Date ____________ Time ____________

Daily documentation (Locations starting with northern most, working left to right)

Observation/sampling sequence: “Tip of nose to tip of tail”. Anterior to posterior; proximal to distal; dorsal then ventral; left then right.

2. Torso: dorsal then ventral (whatever can be observed)
3. Left front leg; right front leg
4. Left rear leg; right rear leg
5. Anal area
6. Tail

- As cavity opens, organ ID and decomposition descriptions (desiccation stage, etc; below*) of organs will be worked anterior to posterior.

- As external tissue (hair, hide, etc) falls away or is scavenged exposing underlying soft tissue and bones, those exposed areas will be ID and described following the above sequence and desiccation (below*).

Early decomposition/describe appearance (moist/dried, clear/opaque, stiff/flexible, loose/tight, drooping from gravity, etc):

Eyes __________________________________________ Ears _________________________

Tongue/mouth/lips _________________________________________________________

General: livor mortis or other skin discoloration, rigor, etc. ______________________

Note hair loss following above observation sequence ____________________________

Odor mid ventral, one foot from carcass (circle): Normal, Faint (pre putrefaction), Mild, Moderate, Strong, Moderate, Mild, Faint (post), None _____________________________

Decomposition stage (circle): Fresh, Bloat, Active decay, Advanced decay, Dry, Remains ________________________________

*Note desiccation following above observation sequence (circle): Fresh, Intermediate, Dry, Mummified __________________________

Disarticulation: head, legs, shoulder girdle, pelvic girdle, vertebral/tail; Fully intact/attached; Partially attached by soft tissue; separated __________________________