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DEFINING POSTMORTEM CHANGES IN WESTERN MONTANA: THE EFFECTS OF CLIMATE AND ENVIRONMENT ON THE RATE AND SEQUENCE OF DECOMPOSITION USING PIG (*SUS SCROFA*) CADAVERS

By

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Defining Postmortem Changes in western Montana: The effects of climate and environment on the rate and sequence of decomposition using pig (*Sus scrofa*) cadavers
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Abstract

The rate and sequence of human decomposition permits forensic anthropologists to estimate time since death for remains from the forensic context. Preliminary research conducted in western Montana indicates that decomposition does not follow the patterns found in other geographic locations. The purpose of this study is to better define western Montana's unique environmental factors that affect the rate and pattern of decomposition by documenting changes in mature pigs (*Sus scrofa*) employed as human proxies. The pigs were deposited during the cold months of October and December and analyzed by comparing the rate and sequence of decomposition with climatological and environmental variables. The popular method of calculating accumulated degree days (ADD) to estimate time since death was tested and found to consistently underestimate the actual day of death, indicating that without alteration, this method should not be relied on for remains that have decomposed in western Montana. The results from this study confirms that Montana's cold winter slows and eventually halts decomposition, which in turn affects how remains decompose after the spring thaw. Ultimately both specimens reached complete mummification, never achieving skeletonization by the end of the study. The overall purpose of this study is to contribute to building a baseline data set for documenting decomposition in western Montana's highly variable and unpredictable weather.

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CHAPTER 1: INTRODUCTION

Research conducted by forensic anthropologists on the rate and sequence of human decomposition can help law enforcement estimate time since death of an individual in a criminal case (Haglund and Sorg, 1997a; Haglund and Sorg, 1997b; Komar and Buikstra, 2008). The rate and sequence of human decomposition is affected by many environmental factors which has resulted in extensive research to more accurately understand the forces affecting decomposition. However, little is known about the environmental factors that affect decomposition in western Montana. There have been a few studies using pigs (*Sus scrofa*) as a human proxy in Montana (Terneny, 1997; Gonder, 2008; Dudzik, 2009; Parsons, 2009). Gonder, Dudzik, and Parsons's studies were all conducted within the Lubrecht Experimental Forest 30 miles east of Missoula at an elevation of 4300 feet. The results of the studies indicate that the environment of western Montana affects the rate and sequence of decomposition differently than other geographic locations. Very little research beyond Terneny (1997), has been conducted in the populated area of the Missoula Valley which warrants this study to further investigate the rate and pattern of decomposition in this location.

There are 3 main goals associated with this project. The first is to collect data to contribute to a baseline understanding of the rate and sequence of decomposition in western Montana. The second is to collect and record entomological data from decomposition in the western Montana. The third goal is to provide information that will enhance law enforcement investigations in western Montana.

The conclusions for this study come from answering the 4 main objectives of this research. The main objective of this study is to compare the decomposition of two pigs (*Sus scrofa*) placed

on the ground surface during different months, October and December. This will show the differences in rate and sequence of decomposition are due to different environmental factors that occur in October and December. The environmental factors considered include temperature, humidity, precipitation, wind, and insect activity.

The next objective is to compare the decomposition of the two pigs placed in the Missoula Valley to the two pigs previously placed during the same months within the Lubrecht Experimental Forest. This will show how the different environmental factors affect the rate and sequence of decomposition in two different locations in western Montana. The environmental factors considered are altitude, temperature, humidity, insect activity, and rain and snowfall.

Also important to this study is to be able to identify visual cues of cold weather induced stasis in the decomposition process to better estimate the postmortem interval (PMI) in western Montana. Research has been conducted that shows indicators of remains freezing and thawing; however, little research has focused on visual signs that indicate how long remains have been frozen. Remains exposed outdoors in the Montana winter freeze and look fresh longer than expected, making an estimation of time since death very difficult.

The last objective of this research is to test the Megyesi et al. (2005) method of calculating ADD in the western Montana. Megyesi and colleagues found a case from Missoula to be an outlier in their analysis due to unknown environmental variables. Variables that affect decomposition in western Montana need to be better understood. The Megyesi et al. method may need to be adjusted to better estimate time since death in this environment.

CHAPTER 2: LITERATURE REVIEW AND PAST RESEARCH

Forensic anthropology, a subdiscipline of physical anthropology, specializes in skeletal analysis and human identification in a medicolegal context (Haglund and Sorg, 1997a, 1997b; Reichs, 1998; Komar and Buikstra, 2008). The predecessor of forensic anthropology can be traced back to18th century European anatomists who began studying and making observations about the skeletal system and began working with ideas like skeletal growth, human variation, stature estimation from long bones, and the creation and implementation of skeletal measuring devices still in use today (Ubelaker, 2006). In the late 19th century Harvard anatomist, Thomas Dwight, was credited with being the father of American Forensic anthropology due to his use of forensic anthropology methods in a medicolegal context. This lead to the work of influential anthropologists in the field such as Ales Hrdlicka and the creation of the American Association of Physical Anthropologists and the American Journal of Physical Anthropology and Wilton Krogman bringing attention to the profession.

Forensic anthropology was officially defined as "that branch of physical anthropology, which, for forensic purposes, deals with the identification of more or less skeletonized remains known to be, or suspected of being, human" by T.Dale Stewart (1976, found in Ubelaker, 2006, p 4) and expanded upon by Clyde Snow (1973, found in Ubelaker, 2006, p 4) he added to the definition "problems of medical jurisprudence." Military conflicts increased the need for skeletal identification and better methods were created by T. Dale Stewart, Mildred Trotter, and T.W. McKern vastly enhancing the field of forensic anthropology. Forensic anthropology has been, and still is a rapidly growing discipline with constantly improving methods and theory.

One responsibility of a forensic anthropologist is to interpret taphonomic changes, or what happens to an individual's remains after death (Haglund and Sorg, 1997a, 1997b; Ubelaker, 1997). Taphonomy was originally defined in 1940 by Efremov as the "laws of burial" and in 1989 Bonnichesen included "the accumulation and modification of osteological assemblages from a site formation perspective" (found in Haglund and Sorg, 1997a, p 3). Forensic taphonomy is often qualitative in nature and investigates the events that modify a body perimortem (around the time of death) and also postmortem (between death and when the remains are found), and also what the environment was like during decompositional events (Haglund and Sorg, 1997a, 1997b; Ubelaker, 1997; Sorg and Haglund, 2002). A major focus in taphonomy for forensic anthropology is the information regarding soft tissue changes and environmental and biological factors that affect the rate and sequence of human decomposition. This knowledge of taphonomic events can be used to estimate the postmortem interval, which can be used to aid law enforcement with cases involving human remains. Haglund and Sorg (1997b) and Clark et al., (1997) warn that although in most cases the sequence of postmortem change can be predictable, the time frame in which they occur is not. In 2002, Sorg and Haglund encouraged forensic anthropologists conducting forensic taphonomy research to generate more accurate data from case specific environments and to share results to gain a better understanding of taphonomic processes.

A forensic anthropologist's main goals are to locate and recover remains using archaeological methods, interpret and document the forensic context in which remains are found, perform analyses on partial or fully skeletonized remains with the intended results of a positive identification of the remains, and the interpretation of perimortem and postmortem events affecting the skeletal remains (Mann et al., 1990; Dirkmaat et al., 2008). A biological profile is

created and compared to missing persons lists or the suspected victim/s. To perform this task it helps a forensic anthropologist to know how long the person has been dead. Understanding the patterns (the sequences of stages of decomposition) and rates (how long each stage lasts) of decomposition gives forensic anthropologists a better ability to narrow down the appropriate time of death enhancing the identification process. Not only are the rates of decompositional change extremely variable, but the pattern in which decay occurs can vary depending on the specific location and differential environments the remains are decomposing in (Ubelaker, 1997).

Decomposition is a complex process, however generalized stages and rates are well known. Forensic anthropologists need to understand the basic concepts of decomposition to better identify how specific variables affect postmortem changes. Early postmortem change occurs around two hours after death due to the lack of circulation of oxygenated blood resulting in lighting of skin color, muscle relaxation which may result in loosening of the sphincters and purging of stomach contents (Clark et al., 1997; Pinheiro, 2006). The eyes begin to change internally by the coagulation of blood in the vessels causing what is referred to as "sausaging" and externally by the drying of tissue leaving a "banding." Carbon dioxide starts to build up in the veins and arteries increasing acidity and resulting in clotting of the still blood in the vessels. This usually corresponds with the stiffening of the muscles known as rigor mortis. When the muscles finally relax out of rigor, enzymes in the blood called fibrinolysins cause the blood to reliquefy. Next the body enters late postmortem changes occurring 2-4 hours after death. Three important events occur usually concurrently without influencing one another: rigor mortis, algor mortis, and livor mortis.

Rigor mortis is a chemical reaction in the skeletal muscles usually starting 2-3 hours after death making the muscles rigid (Clark et al., 1997). Within 24 hours all muscles in the body can

be stiff until usually at about 48 hours the chemicals are all released causing the muscles to be flexible again. Clark et al. (1997) warn that if the body is warmer than normal at the time of death rigor may happen at a quicker rate. Algor mortis is when the body's metabolic internal temperature regulating system stops and the body cools down to match the temperature of the environment it is placed in. In ambient temperature cooler than normal living body temperature this decrease in body temperature has been found to occur at 1.5°F an hour, though recent research has shown that the rate of temperature decrease is dependent on factors like amount to body fat, clothing present, and if the remains are wet (Wardak and Cina, 2011). Livor mortis or lividity occurs when the blood ceases to be pumped throughout the vascular system. After the blood stills, gravity causes it to pool in the body towards the ground. This phenomenon is usually seen about 2 hours after death has occurred. The oxygen in the hemoglobin found in the red blood cells begin to break down causing deoxyhemoglobin to occur manifesting in the body as a red to purple color which increases in darkness over time. If the body is placed in a cold environment deoxyhemoglobin cannot occur leaving the body to be a very pink color. Lividity can become fixed at about 4-6 hours after death, meaning that the body fat solidifies trapping the blood where it lies in the dermis.

Decomposition is the breakdown of soft tissue after death and consists of two events called autolysis and putrefaction (Clark et al., 1997; Pinheiro, 2006). Early in the postmortem process the low levels of oxygen in the body causes the pH of the cells to lessen resulting in the release of enzymes that are stored in the lysosomes into the cytoplasm of the cells. The release of this enzyme is called autolysis. These enzymes start to devour the proteins and carbohydrates and eventually spill out of the cellular membrane feeding the bacteria that are unregulated after death. Autolysis occurs in all cell types but can be seen earlier in the postmortem process in cells

that naturally produce more lysosomes. Cold temperatures can halt autolysis from occurring after death, however hot temperatures can speed up this process causing cellular destruction to happen at a much faster pace than normal. Autolysis manifests itself externally by breaking down skin cells and causing skin slippage of the epidermis and postmortem bullae or pockets of fluid that collect under the skin. Internally autolysis of the red blood cells, called intravascular hemolysis, stain the superficial vessels and as a result of the purple/blue color caused by deoxyhemoglobin, this produces what is called marbling that becomes visible on the skin.

Soon after death the natural bacteria and fungi found in the body during life are left unregulated and start to eat the proteins, carbohydrates, and fats that are freed during autolysis producing gases and odors in a process called putrefaction (Clark et al, 1997; Pinheiro, 2006). Blood cells feed this gas producing bacteria causing more gas to collect which leads to bloating of the head, abdomen, and eventually the limbs. Also the pressure that builds up in the abdomen can cause bloody fluid and tracheobronchial foam to be discharged out the nose and mouth (Pinheiro, 2006). A chemical produced by bacterial gas, called hydrogen sulfide, interacts with hemoglobin and can produce a green color referred to as sulfohemoglobin and usually occurs more frequently where blood has pooled in the vessels during lividity (Clark et al, 1997; Pinheiro, 2006). Also during this postmortem period, purging of decaying tissue from the gastrointestinal tract can occur from the nose and mouth as a result of the pressure increasing from the remains bloating. Autolysis and putrefaction alone can skeletonize remains; however animals, insects, and environmental factors usually have an important role helping remains reach skeletonization.

Natural preservation processes can occur during decomposition that slow or prevent the remains from reaching full skeletonization, including saponification and mummification

(Pinheiro, 2006). Saponification can occur causing a yellow, gray, or off-whitish wax-like substance to form called adipocere (Mellen et al., 1993; Forbes et al., 2004; Pinheiro, 2006; Notter et al., 2009). Adipocere is the byproduct of the chemical breakdown of subcutaneous adipose tissue. The triglycerides found in adipose tissue go through hydrolysis causing the release of saturated and unsaturated fatty acids. Hydrogenation of the unsaturated fatty acids occurs to produce more saturated fatty acid that interacts with the chemicals given off from the body during autolysis or found naturally in the environment the remains are deposited in creating the sold waxy adipocere. It is an irregular process that can appear in a variety of environments, warm and damp, dry, burials or crypts, and in warm or cold water. The estimated time for adipocere to form is debated amongst scientists, some say it takes a little less than a month all the way to a few years (Notter et al., 2009). A study documenting the formation of adipocere conducted by Notter and colleagues (2009) found that in a controlled environment adipocere can form in a month given the right conditions. Forbes et al. (2004) studied the chemical breakdown of *Sus scrofa* adipose tissue to find that the formation of adipocere did not have a correlation to the sequences of decomposition; it was more dependent on the environment in which the remains are placed. Adipocere can co-occur with other decompositional events, for example it can happen alongside putrefaction and also mummification (Mellen et al., 1993).

Mummification is the drying of soft tissue (Clark et al., 1997; Pinheiro, 2006). Desiccated tissue is usually brown in color and can be caused by a dry environment that has adequate air ventilation. It can also occur in icy cold environments that prevent bacteria from growing. Ambach and Ambach (1992) claim that complete mummification of a frozen cadaver is possible when covered by snow due to snow's ability to allow adequate air through to dry out the soft tissue. Pinheiro (2006) cautions that research on the time it takes to produce mummification has

not been adequately studied. Due to soft tissue preservation both saponification and mummification may help forensic anthropologists and pathologists with identification and also finding cause of death, though mummification preserves evidence better than saponification.

An important component of decomposition is insect involvement in the decay process. A study by Simmons et al. (2010) suggests that insect involvement is the most important factor affecting the rate of decomposition. Forensic entomology is a branch of entomology that uses the understanding of the life stages and behavior of insects in a medicolegal context (Haskell et al., 1997). Arthropods have a huge effect on postmortem changes because they remove soft tissue affecting the rate of decomposition. Understanding the factors that affect how fast insects go through their lifecycles gives forensic entomologists and forensic anthropologists a better interpretation of the scene where decomposing remains are found.

Arthropods, like flies (Diptera) and beetles (Coleoptera), can be very useful in estimating time since death and are also helpful reconstructing the environment remains have decomposed in (Haskell et al., 1997). Blowflies (Calliphoridae) are the insects found most often around decomposing remains; different species of blowflies can be found in different geographic locations and environments. Some other forensically important flies are flesh flies (Sarcophagidae), humpback flies (Phoridae), cheese-skippers (*Piohila casei*), soldier flies (Stratiomyide), and house flies (Muscidae). Forensically important insects have been studied in depth and by knowing the temperature and environment of the scene and the species of insects found, forensic entomologists can get accurate postmortem time estimation by using the life cycle of the insects.

Flies are usually the first insects on the scene, responding within minutes (Haskell et al., 1997). Female flies lay eggs (oviposit) fairly quickly in moist sun protected areas such as the nose, mouth, open wounds, genital areas, and between the body and the ground. Temperature dependent, the eggs usually hatch within a few hours. Fly larvae, or maggots, grow in three stages instar 1, instar 2, and instar 3. Maggots in instar 1 are very small and eat smaller amount of soft tissue; they shed their exoskeletons and move into instar 2. Maggots in instar 2 are medium size and only stay in this stage for about 8-10 hours. By this time the remains should be in autolysis making the soft tissue a better food source for the maggots increasing the amount they eat. The exoskeletons are shed for the second time going into instar 3. At this time the maggots have an insatiable appetite consuming mass amounts of soft tissue and their high activity produces heat up to 77°F (25°C) above the ambient temperature (Haskell et al., 1997; Simmons et al., 2010). Energy is being stored at this time to prepare for metamorphosis. Maggots migrate away from the body to pupate; Haskell et al. (1997) notes pupa casings have been record up to 150ft away from the body. They bury into the soil or ground vegetation where their body shape changes to a shorter wider oval. The hard exoskeleton protects the maggot as a shell and during the metamorphosis changes colors from off-white, to reddish maroon, brown, and then black. This color change can be useful in aging puparia (pupa casings). Three to five days later immature flies emerge colorless and weak from the anterior end of the puparia. Eventually enough blood is pumped through the body to change the flies to a metallic color and they can begin to fly. It takes 3-5 days to reach sexual maturity and this process can start all over again.

Beetles also play a large role in decomposition, though different from flies (Haskell et al., 1997). Beetles such as rove beetles (Staphylinidae), hister beetles (Histeridae), and hydrophilid

beetles (Hydrophilidae) are attracted to remains 1-2 days after death as they eat the fly eggs and larvae. Carrion beetles (Silphidae), hide beetles (dermestids), and sap beetles (nitidulids) eat primarily the drying soft tissue of remains in advanced stages of decomposition. The last wave of beetles appear when the remains are reaching skeletonization, they include skin beetles (trogids), darkling beetles (tenebrionids), and red-legged ham beetles (*Necrobia rufipes*). Overall beetles appear later than flies but stay longer. Their life cycles can be useful in the estimation of postmortem interval, however not as accurate as using fly life cycles because beetles can change their 9 instars to 5-7 instars if food is scarce causing the estimation to be a little off. Other forensically important insects that have minor roles in the decomposition process are bees, wasps, and ants (Hymenopetera), butterflies and moths (Lepidoptera), and mites (Acari).

There is other important information that can be learned from investigating the insects. By looking at pupa casings from flies and also exoskeletons from beetles, trained forensic entomologists can tell what season the individual decomposed in giving a better time estimation of how long the remains have been decomposing for (Haskell et al., 1997). The specific species present may be an indication of the type of environment the remains have decomposed in. Certain species of insects are only found in distinct locations. This may be an indicator of a secondary deposit site if there are species not native to the area found on the remains. Haskell and colleagues (1997) explain that interrupted stages of insects or different size and ages of maggots may indicate that something happened to the remains that caused the insects to not follow their expected patterns. They suggest this is an indication that the remains have been moved sometime during the decomposition process. Areas of trauma can be seen by looking at maggot masses. Female flies are attracted to the 9 natural orifices to lay their eggs. If a maggot

mass is an unexpected place on the body, it may be due to an unnatural entrance usually created by trauma of some sort.

Many external variables along with idiosyncratic variation of the individual affect the rate and sequence of events that a body goes through after death (Clark et al., 1997; Sledzik,1998; Pinheiro, 2006). Mann et al. (1990) state that variables affecting decomposition rates and sequences are complexly intertwined while Pinheiro (2006) claims that many researchers believe that predicting time intervals for the stages of decomposition cannot be estimated due to the overwhelming factors that affect postmortem destruction. However, Haglund and Sorg (1997a) support the idea that independent variables can and should be investigated to understand the process of decomposition, especially when it comes to how the environment causes change to soft tissue and bone.

Mann et al. (1990) claim that ambient temperature is the most important variable affecting decomposition. Temperature affects the flies by halting the laying of eggs between 40°F to 50°F and causing death to occur to un-hatched eggs at 32°F and below. Cold weather can prevent decomposition from occurring and in some cases turn the skin an orange and/or black color often occurring with mold growth. Warm weather can increase decay with the whole cycle occurring in 2-4 weeks. It is the most difficult to accurately estimate the postmortem internal when the ambient temperature is irregular. How humid or arid the location is also affects decay. Insects, like maggots, thrive in more humid environments increasing decay. Arid environments can cause desiccation of soft tissue decreasing decay. Mann et al. state that mummification as a result of aridity during cold weather can result in the preservation of majority of the skin and can stay mummified 2-6 years. Rain can slow down the laying of fly eggs but does not affect maggot activity. Areas of trauma on the body will attract female flies laying eggs; with this additional

area supporting a maggot mass the rate of decomposition can be increased (Mann et al., 1990; Pinheiro, 2006). Insect access or types of insects found in a location can affect the rate of soft tissue destruction (Mann et al., 1990; Haskell et al., 1997). Carnivores and rodents can eat soft tissue decreasing the time it takes to reach skeletonization; whereas avian scavengers can eat the maggots decreasing the rate of decay (Mann et al., 1990). The specific makeup of the individual's body chemistry may affect decomposition rates (Sledzik, 1998), along with other idiosyncratic traits that can increase decomposition, like an increased amount of bacteria in the body at the time of death (Pinheiro, 2006). The surface the body is placed on, along with the presence of cultural alterations like clothing or embalming has an impact of postmortem decay (Mann et al., 1990).

Forensic anthropologists are very aware that variables affecting decomposition need to be better understood to be able to solve cases and the best way to understand the postmortem processes is to conduct research in their specific environments by looking at how different variables affect decay (Micozzi, 1986; Bass, 1997; Galloway, 1997; Micozzi, 1997; Komar, 1998; Rhine and Dawson, 1998). Bass (1997) realized the need for decomposition studies resulting in the creation of the Tennessee Anthropology Research Facility (ARF) used to conduct experiments trying to understand the process and variables of decomposition. He is a big advocate for geographic specific research and encourages more research to be done and published. Through his research he has found that during the Tennessee summers, which can have high percentages of humidity and ambient temperatures of 80-90 ° F (27-32°C), cadavers, can reach skeletonization in two weeks. He points out that the decay process is expected to slow in the winter but does not go into detail about the variables causing this to happen. He does mention that mummification can and does occur in Tennessee when maggots in direct sunlight

leave a protective covering of soft tissue over them while they eat resulting in dehydration of the skin.

Galloway (1997) also stresses the importance of doing location specific decomposition studies as most of the cases in Arizona do not follow the rate and sequence laid out in Tennessee. Arizona's arid summers average over 100°F (38°C) during the day and still stays warm during the night. Winter days are usually between 60-69°F (27-32°C) and almost reaches freezing at night. Galloway studied 468 cases from the area to better understand the decay in this microenvironment. She found that a lot of variation occurred in postmortem changes depending on the variables involved, though some generalities were found. The high ambient temperatures caused remains to rapidly start decomposing; however, the low humidity causes the outer skin to mummify quickly while the tissues under the skin still decompose. After two months complete skeletonization can occur, although two-thirds of the cases had evidence of animal scavenging. Galloway notes that during the winter months decay rates slow down yet the pattern of postmortem changes is the same. She also points out the importance of knowing how the microenvironment affects the rate and sequence of postmortem decay to be able to see when remains do not follow the expected pattern and understanding that something is causing this deviation, she used the example of remains having been frozen for a period of time.

Rhine and Dawson (1998) emphasize that the patterns of decomposition are relatively the same everywhere, it is the rate of decomposition that needs to be looked at in other geographic locations to understand how variables specific to those environments affect decay. They studied cases from New Mexico to try and find methods to better estimate time since death. New Mexico is a large state with extremely variable environments ranging from -30°F (-35°C) to 102°F (48°C). They found that remains can start to skeletonize in 3 weeks in warm weather and that

cold weather and higher altitudes slows down the expected rate. Complete skeletonization can be reached in 1 month with animal scavenging and 2 months without scavenging. Mummification has been a source of confusion in New Mexico as some individuals will mummify and others will not. Rhine and Dawson suggest that the environment needs to be just right for desiccation to occur, slightly damp environments with slightly cooler ambient temperatures and is seen more in the area with higher altitudes. They ultimately find that time since death can most accurately be estimated by comparing the state of the remains to a chart of expected decay rates found in the specific location, and the way to do this is to conduct research to document the occurrence of variables in each microenvironment.

Komar (1998) discusses that the effect of cold temperatures on the decomposition process is poorly understood. It had become obvious that remains decomposing in cold environments did not match the decomposition rates that were being seen in other research locations like Tennessee. Komar looked at 20 cases from Edmonton, Alberta to try and better understand how cold and freezing temperatures affect decay. She found that during the warmer summer months remains could skeletonize in 6 weeks, whereas during the 5 months of the year in which the temperatures were below freezing it takes about 4 months to skeletonize. It is noted that 16 of the 20 cases showed moderate to extensive animal scavenging, most likely affecting the rate of skeletonization.

Micozzi (1986; 1997) specializes in cold weather decomposition. He compares the rate and sequence of decay of remains that have been previously frozen before decomposition to remains decomposing right after death occurred to better understand how cold weather affects time since death estimations. He found that ambient temperatures below 39.2°F (4°C) stop the process of decomposition, bacteria growth is halted, and soft tissue is preserved and as a result postmortem

changes become static. After frozen remains thaw and start the decay process there is less bacterial activity which causes a dramatic decrease of putrefaction. It was also noted that though putrefaction was less in thawed remains, the actual stage of putrefaction lasted longer than seen with fresh remains. The higher levels of bacteria found in fresh remains causes the body to decompose from the inside outwards as a consequence of increased putrefaction. Micozzi also states that an indication that remains were frozen before decay is the appearance of decomposing from the outside of the body inward. The mechanical action of freezing the cells in the tissue results in weakening of the skin and connective tissue. This combined with the skin being the first to thaw giving access to organisms to start the decay process on the outside of the body first. He also found that the breakdown of tissue can lead to earlier disarticulation of skeletal remains than seen with fresh remains. In addition, he found that thawed remains have more rapid hair loss, more mummified soft tissue is present, more insect activity, and will have artifacts of ice crystals in tissue cells. He warns that remains that have been frozen can greatly alter the estimation of time since death because of the perplexing ways the variables are affected and react with one another.

Schoning (1992) was interested in the affects freezing had on soft tissue. She took normal skin from a pig and compared it to pig's skin that was frostbitten antemortem and pig's skin frozen postmortem to see if there was a way to tell when freezing had occurred. She found that that skin frozen before death showed distinct signs of trauma. The skin turned a dark purple color and formed pockets of fluid in the epidermal cells (vacuolation of keratinocytes) most likely caused by ice crystals, swelling of the dermis, and dilation of the capillaries in the skin. Skin frozen after death showed slight differences from the normal skin that had not been frozen. The

important differences were the epidermis was more condensed, the nuclei of the epidermal cells were more stretched out, and the cells reacted better to being dyed (basophilic).

Megyesi et al. (2005) saw the need to try and find a correlation between ambient temperatures and decomposition rates to better calculate how long an individual has been dead. Traditional ways of estimating the postmortem interval (PMI) are qualitative methods using observations of the decomposition process, to make decomposition observations quantitative and able to use in statistical analyses, accumulated degree-days (ADD) were used in this study. ADD is the available heat units needed to achieve decomposition. To score observations Megyesi et al. (p.2) used a modified version of Galloway et al. (1989) visual stages of decomposition by creating 4 categories 1) fresh, 2) early decomposition, 3) advanced decomposition, and 4) skeletonization. Each category is broken down into sequential observations for that stage and each observation is given a score. The body is divided into 3 anatomical areas 1) head and neck 2) trunk 3) limbs, hands and feet and the three areas are scored independently of each other. By adding up all three areas the total body score (TBS) is calculated. To calculate ADD, the TBS is placed into a regression formula resulting in the number of accumulated degree-days. The next step is to find the average daily ambient temperatures from the location the remains were found, temperatures below 32°F (0°C) are counted as 0. Start on the day the remains were recovered and add together the average temperatures for each day moving backwards in time until the average temperatures add up to the number calculated for the ADD. That day the ADD number is reached is the estimated day that death occurred, give or take the standard deviation.

Three-fourths of the cases used in Megyesi et al.'s (2005) study decomposed during the warm months of May through September and there were no cases from December. One case from Indiana decomposed in the late winter and was found to be an outlier in this study. They

suggested it was due to the fluctuating temperatures of freezing at night and warming up during the day. As mentioned earlier, when looking at visual observations it is the most difficult to estimate PMI when ambient temperatures fluctuate between warm and cold (Mann et al., 1990) and this may be an indication that using ADD does not solve this estimation problem. The other outlier in this study was the case from Missoula, Montana. Megyesi et al. suggest it may have deviated from the expected outcome as a result of environmental specific factors that affected decomposition differently, possibly variables like altitude or rainfall. Cases for this study were collected from all across the United States, however most were from Indiana and Illinois. They encourage researchers to test ADD in their specific environments and during different seasons to improve the formula for those different locations. Initial research in western Montana has been conducted to investigate what specific factors affect decomposition in western Montana that makes Missoula an outlier when using the Megyesi et al. method of ADD (Dudzik, 2009; Parsons, 2009).

The need for geographic specific decomposition research in Montana has become very apparent. Montana's microenvironment is unique in that the weather is extremely variable throughout the four seasons. Montana covers about 146,318 sq. miles with elevations of 1,800 to12, 800 ft. and is divided into western and eastern climate zones by the Continental Divide (Caprio and Farnes, 2006). Western Montana is mountainous with deep valleys, whereas eastern Montana also has some mountains but is mostly hills and rolling plains. Temperatures vary throughout the state but usually eastern Montana has colder winters, hotter summers, and more wind. As a result of western Montana's deep valleys, summer nights are usually windless and cold, also during the winter months fog and clouds collect in the valleys. Depending on the location, Montana gets from 9.07-105.0 inches of rain a year with the rainy months being in late

spring early summer. Relative humidity in Montana has an inverse relationship with ambient temperature. The humidity is the highest, about 75%, when the temperature is the lowest usually right before sunrise. The humidity is the lowest during the day when the temperature is the highest, less than 35% in the summer and around 70% in the winter. During the warm months thunderstorms occur and can be accompanied by hail and high winds; while during the colder months snowstorms and blizzards occur. The first freeze of the year usually happens in September while the last freeze usually occurs in May.

Previous decomposition studies have been conducted in western Montana with results that indicate the decay processes do not follow expected rates documented in places like Tennessee, Arizona, New Mexico, and Alberta (Terneny, 1997; Wagster, 2007; Gonder, 2008; Parsons, 2009; Dudzik, 2009). Terneny (1997) was the first to look at decomposition rates and sequences in western Montana. She was interested in comparing postmortem changes that occurs in this geographic location to other studies done in different environments. The results of this study followed the same patterns but the rate at which the remains went through the stages of decay was different. Terneny's study began on April 5, 1996 in the Missoula Valley. She placed an unprotected adult pig on the ground and buried an adult pig 60cm deep to record the decay rate and patterns. For this particular study the results of the surface deposition are of interest. She found that the remains stayed in the fresh stage for 3 days before entering the early stage of decomposition which lasted for 7 days. The specimen then stayed in the advanced stage of decomposition for 27 days before skeletonization occurred. Skeletonization lasted for 105 days before Terneny classified the remains as in extreme decomposition for the last 157 days of the study. Throughout the study signs of animal scavenging were present, however at day 209 the

remains were drastically scavenged and scattered. She concluded that the weather, different insects, and animal scavenging lead to different rates of postmortem changes.

Gonder (2008) was interested in more accurately estimating time since death of animals used for cases against poachers. She studied postmortem changes of 8 gray wolves, 4 mountain lions, 2 black bears, and a white-tail deer also using Lubrecht Experimental forest for the study location. Gonder set up research protocol and methods that have since been followed for decomposition research in western Montana and has been used in this current study. What is interesting about Gonder's study is she looked at postmortem decay during all 4 seasons resulting in a well-rounded understanding of the effects Montana's unique environment has on the decomposition of animals in the Lubrecht Experimental Forest. She found that cold weather does induce stasis in the decomposition process and that after being frozen some animals did not bloat as much as expected. Summer and early fall animals were the only specimens to follow expected rates and sequences of decay.

Wagster (2007) was the first person to study how Montana's randomly fluctuating and sometimes extreme winter weather affects the rate and sequences of decomposition. Her study was conducted in Lubrecht Experimental Forest located 25 miles east of Missoula at an elevation of 4,300 ft. There were 4 wolf carcasses used and all 4 had been previously frozen before deposited; 2 wolves had reached the dry stage before winter and 2 were deposited at the onset of winter. Wagster found that the cold weather affected postmortem changes by slowing down the rate of decay; wolf 3 spent 6.5 months in advanced decay and wolf 4 spent 5.5 months in advanced decay. Both never reached the dry stage before the end of the study, negating the theory that freezing and thawing drastically speeds up the rate of decomposition. She also found that maggots could over-winter inside the remains becoming more active when the temperatures

warmed up enough. Another observation she made was that both of the cold weather wolves had pink teeth in the beginning of decomposition.

Parsons (2009) used pig specimens to start creating a baseline dataset for west central Montana. From this study subsequent studies have followed, including this one. Parsons deposited two pigs on the ground in protective cages at Lubrecht Experimental Forest, one August 6, 2008 (LSS-1) and October 13, 2008 (LSS-2). She found that LSS-1 followed the same sequences that were expected from studies done in other locations; however, the rates of the postmortem changes were still slower than expected. LSS-1 started into the early decomposition stage on day 2 lasting for 5 days. The specimen then moved into the advanced stage of decomposition where it stayed for 244 days, until the completion of the study. She found that the remains mummified and looked the same on day 123 as day 250. LSS-2 was different as a result of the cold ambient temperature, which drastically slowed down the rate of decay. LSS-2 stayed in the fresh stage of decomposition until day 180 due to cold weather induced stasis. After the remains thawed they stayed in the early stage of decomposition for 54 days before moving into the advanced decomposition stage for 40 days, until the conclusion of the study. Parsons also noted a decrease in insect activity on LSS-2 compared to her LSS-1. Parsons tested the Megyesi et al. (2005) ADD method on both of her pigs. She concluded that as time increased so did the accuracy of ADD.

Dudzik (2009) focused her research on how west central Montana's cold winter weather affects decomposition. She used Parson's (2009) October pig (LSS-2) and placed another pig out November 20, 2008 (LSS-3) to compare the rates and patterns of decay. LSS-3 promptly froze solid and stayed in the fresh stage of decomposition for 146 days. After the thaw, the specimen stayed in the early stage of decomposition for 53 days before entering into the advanced stage of

decomposition in which it remained for 42 days until the end of the study. Dudzik also found that the Megyesi et al. (2005) ADD method gave inaccurate PMI estimations due to the early mummification and never reaching skeletonization. She suggested that the scoring for the total body score needs to be adjusted for the area. This current research picks up after Dudzik's study, looking at how cold weather affects decomposition in the Missoula Valley, to further add data to the dataset that was started by Parsons and Dudzik.

CHAPTER 3: MATERIALS AND METHODS

Theory

Sorg and Haglund (2002, p 20) define forensic taphonomy as a "theoretical umbrella for interpreting postmortem processes in context." Forensic taphonomy has a multidisciplinary history in which the methods and theory most commonly used are adapted from other disciplines. The two theoretical methods most relevant for this research are the Forensic Taphonomic Model (Haglund and Sorg, 1997b) and the Experimental Taphonomic Model (Sorg and Haglund, 2002). Most often taphonomic knowledge is generated from inferences made by forensic anthropologists while working on cases or comparing a series of cases. The second and increasingly more popular way to understand forensic taphonomy is to conduct field studies and controlled experiments.

When conducting taphonomic research forensic anthropologists follow the Forensic Taphonomic model which looks at the context in which changes occur to the remains and consists of 4 factors 1) object, 2) space, 3) modification, and 4) cultural influences (Haglund and Sorg, 1997b, p 18). This research is set up following this model where the objects are the remains of two adult pigs (*Sus scrofa*), space being two surface depositions, modification being the time periods the remains were deposited in the cold months of October and December, and cultural influences include the cause of death being projectile trauma to the frontal bone and transportation to the deposition site by trailer. Although observer bias is always an issue, measures have taken to limit investigator and analysis biases. The Forensic Taphonomic model includes two types of studies, cross sectional studies and longitudinal studies. Cross sectional studies capture a taphonomic event at a certain period of time; an example being a forensic case,

the recovery of remains marks an exact moment in the taphonomic process. Longitudinal studies look at the whole taphonomic process over time, an example being a field experiment looking at the rate and sequences of decomposition from death until more advanced stages of decay. Haglund and Sorg (1997b) promote that more longitudinal studies need to be done in forensic taphonomy to test the inferences made by forensic anthropologists looking at case studies.

The Experimental Taphonomic model is also referred to as actualistic research (Micozzi, 1991; Sorg and Haglund, 2002). Actualistic research is an experiment that is conducted with the results being applied to real world problems. This model looks at how controlled independent variables affect dependent variables in a controlled experimental environment. Building a research design using this theoretical model can test inferences made by forensic anthropologists, ultimately resulting in a better understanding of taphonomic processes. Haglund and Sorg (1997b) state that experimental studies can be very beneficial, yet caution needs to be taken because some experiments can be too simple compared to what can naturally occur or that it can possibly produce affects that would not occur normally.

This longitudinal experimental study was designed to test two hypotheses 1) remains deposited in western Montana during winter months decompose at a different rate and sequence than remains deposited in other geographic locations and 2) if remains are frozen and stasis occurs in the decay process the remains exhibit visual evidence that both events occurred.

Research Subjects

In actualistic studies looking at the taphonomic processes of decomposition, forensic anthropologists need specimens for their experiments, ideally human remains (Sorg and Haglund, 2002). However, there are many issues when using humans for research and many

forensic anthropologists opt to use nonhuman proxies like pigs (*Sus scrofa*). Pigs make good proxies as their body composition and size are comparable to humans, the lack of fur and similar skin, they are more accessible than human cadavers, and it is also ethically less complicated to use pigs than humans for research. An increasing number of studies have been conducted using pigs as human proxies including Payne (1965), Schoning (1992), France et al. (1997), Forbes et al. (2004), Bunch (2009), and Notter et al. (2009).

Notter et al. (2009) realized the need to conduct research that compares decomposition of pigs to that of humans due to the increase of studies using pigs as human proxies. They studied how adipose tissue breaks down in both pigs and humans to see if pigs make credible proxies. They found that similar processes of saponification creates adipocere, however the chemical signatures given off from both species are a little different. The authors caution that researchers need to be aware that while pigs are possibly the best proxies for human decomposition, they are not exactly the same, and further research needs to be done to look at other areas of decomposition to see similarities and differences.

This study utilizes pigs as human proxies to better understand the rate and patterns of decomposition in western Montana. Two adult female pigs were purchased from the Giles Family Ranch in Fairfield Montana approximately 150 miles from the deposition site; one on October 1, 2011 and one on December 2, 2011. Prior to purchase each pig was dispatched using a .22 riffle, then wrapped in a tarp held by bungee cords, and was immediately transported to the deposition site on a flatbed trailer. The pig placed on October 1, 2011 (SS-1) was an approximately 180lb black pig with a pink thorax. SS-1's time of death was 2:35pm with an internal body temperature of 102.4 (39.11°C). Final deposition of SS-1 took place at 7:00pm. The pig placed on December 2, 2011 (SS-2) was an approximately 160lb pink pig. SS-2's time

of death was 11:15am and she had an internal body temperature of 102.3°F (39.05°C). Final deposition for SS-2 occurred at 5:00pm Data collection concluded a year after each pig was deposited, October 1, 2012 and December 2, 2012.

Research Site

The research site is located approximately 1 mile south of the Missoula International Airport located in the Missoula Valley at an elevation of 3,205 ft. The site is located on a privately owned cattle ranch that is also used to grow hay and alfalfa. The deposition site is in a hay field on a hill top with full sun exposure. Approximately 32 meters to the north of the deposition site is a ravine filled with cottonwood trees and supports a small stream in the spring (Figure 1). According to the United States Department of Agricultural web soil survey (2012) this particular site has a mean annual precipitation of 10-16 inches, a mean annual ambient temperature of 39-45°F, and is frost free for about 100-130 days of the year. It describes the land as well drained hilly farmland with no flooding. This area is classified as a grass valley and the soil is made up of Glaciolacustrine deposits from prehistoric Glacial Lake Missoula. The first 7 inches of soil is made up of silty clay loam, from 7-60 inches the soil is made up of clay. Soil pH was tested at the time of carcass deposition resulting in the neutral score of 7.

Each pig was placed on the ground on its left side with the head to the north and the dorsal side to the west in a 6'x10'x6 prefabricated dog kennel. The kennels were spaced 12ft apart with the doors oriented to the north. Both kennels were enclosed by a 4 wire electric fence that was powered by a Gallagher S17 Solar energizer to detour wildlife and cattle (Figure 2). Avian and rodent scavenging was an issue at the site and to counteract the scavenging 1 inch mesh was attached to the kennel to prevent unwanted animal activity. Due to the large number of

rodents, as a result of being in a field, unfortunately rodent scavenging could not completely be prevented. Other attempts to dissuade rodents included diverting rodents by live traps baited with food and poison next to the cages and the use of a solar powered Wiser Living Gopher and Molemover which are believed to keep rodents away. These methods seemed to lessen rodent activity; however, they did not stop it.

Figure 1: Research site looking toward the west

Figure 2: The two 6'x10'x6 enclosures, SS-1 in the foreground and SS-2 in the background

Data Collection

Galloway et al. (1989, p141) define 5 stages of decomposition that remains sequentially go through: fresh, early decomposition, advanced decomposition, skeletonization, and extreme decomposition. The fresh stage occurs immediately after death, before insects arrive to the remains and before discoloration has begun. Early decomposition is initiated by the start of autolysis and putrefaction. As a result of autolysis, marbling is present along with discoloration of the skin, skin slippage, and bullae formation. Putrefaction causes the remains to bloat and purge body fluid. Usually the conclusion of bloating marks the beginning of the advanced stage of decomposition. During the advanced stage, maggot activity is substantial along with the beginning of partial skeletonization and desiccation of soft tissues. Skeletonization is defined as more than half of the bones being exposed to dry bones. The last stage of decomposition is called extreme decomposition and is the decomposition of the bones themselves by weathering and wear.

Even though the Galloway et al. (1989) method was designed for arid environments, the classification system did not entirely work for the specimens in this study as a result of Montana's cold weather significantly slowing and altering the stages of decomposition. For the purpose of this study, the Galloway et al. method was altered to more accurately reflect the decompositional changes of SS-1 and SS-2 (Table 1). Four stages were used 1) fresh, 2) early decomposition, 3) advanced decomposition, and 4) mummification. The term stasis is used to represent the periods of no change to the remains as a result of the cold temperatures during the winter. Mummification falls under Galloway and colleagues' description of advanced decomposition; however, in Montana remains that are not scavenged most likely mummify (McKeown et al., 2011). This study makes a distinction between advanced decomposition and

mummification of remains to more accurately describe decomposition in this specific geographic location.

Table 1: Modified stages of decomposition and descriptions used to classify postmortem changes

Stages of Decomposition	Postmortem Changes Associated with Stage
Fresh	• Flesh colored with possible light purple lividity • Smell absent • Insects not present
Early Decomposition	• Marbling present with colors changing to pink, darker purple, blue, and green • Strong odor: fecal smell, seafood-like smell of old blood, putrefactive decomposition smell, and ammonia produced by the maggots • Bloating, skin slippage, bullae formation, and purging fluid from orifices • Insects present- maggot masses forming
Advanced Decomposition	• Colors: black, red, orange, brown, tan, and some instances grayish green • Mild odor: still a putrefactive decomposition smell, ammonia from the maggots, and sweet/musty smell of desiccating soft tissue • Deflation of the abdomen and neck- the abdominal measurement less than the starting measurement • Maggots and an increase in beetles and beetle larvae • Some soft tissue desiccation starting to occur
Mummification	• Brown and tan coloring • Mild odor: sweet/musty desiccated tissue smell • Insects: maggots have left to pupate, beetles and beetle larvae still present • Greater than 75% desiccation of soft tissue

Standard procedures of data collection for decomposition in western Montana were established by Gonder (2008); this research utilizes those standards. All data collected was methodically recorded in a field notebook. This form of documentation was chosen due to its flexibility, allowing for the unpredictability of cold climate decomposition better than premade datasheets. Daily notebook entries followed a set protocol created for this specific project. For

each site visit the date, arrival and departure time, how the site was accessed, and any additional individuals visiting the site was recorded. Initial observations about the weather were noted along with general overall observations about the site. The status of equipment was recorded along with performing daily monitoring of battery life and memory space on the time-lapse cameras and dataloggers. For each pig detailed observations were documented including all visual changes to remains, color changes, areas and times of desiccation and saponification, and descriptions of smells. The types, amounts, and locations of insects present on and around the remains were also recorded. Though many attempts were made to prevent rodent scavenging, it did occur, the area on the remains and extent of damage was well documented.

During each site visit the same measurements and temperature readings were collected and recorded for each set of remains. At the time of deposition a metric cloth tape measure was laid on the ground under the pigs' abdomen which was used to measure the amount of daily bloat and deflation that occurred. A TruTemp digital handheld thermometer was used to take ambient temperature readings by the remains. Also, the temperature was taken of the external surface of the remains by pressing the digital thermometer against the right rump. Maggot mass temperatures were also collected when maggots were present, specifically in the posterior end, left hip crease, left axillary region, and in the mouth. ThermoWorks's waterproof Thermadata Series II Temperature Loggers with fixed probes were used to record the ambient temperature at the site. The probes were used to take internal temperature readings of the remains; they were inserted vaginally and held in place by securing the wire of the probe to long nose tweezers embedded in the ground. The data loggers were set to take temperature reading once every two hours and the data was downloaded once a month. A Wingscapes Timelapse PlantCam camera

was set up in the northeast corner of each cage and was programed to capture a picture every 5 minutes.

The site was visited daily until July 2012 with an exception of a few weeks in December and January when the weather made it difficult to visit the site. From July to December 2012, site visits occurred weekly. Most often the site was accessible by vehicle, however due to rain, extreme mud, and snow the site was also accessed by hiking, an all-terrain vehicle, and snowshoes. During every site visit the same procedures were performed in the same sequence. Initial observations were made in regards to both pigs as well as about the site in general and recorded in the field notebook. Next photographs were taken with a Nikon D3100 14.2 MP DSLR. Pictures were taken of the site and the remains from all angles, distances and different body sections. After the pictures were taken the observations previously described were recorded in the notebook for each set of remains. Measurements and temperatures readings were then collected. Before leaving the site batteries were changed and memory cards downloaded and cleared.

Extensive weather information was collected and recorded throughout the field experiment. Visual observations were taken at the time of site visits describing the weather, wind speed, cloud coverage, and ambient temperature. Ambient temperatures were attained by a digital thermometer and by the data loggers at the site. Weather data was collected weekly from the weather station located at the Missoula International Airport which is not only the closest, 1 mile away; it is also in the same microenvironment as the research site.

All data collected are stored in multiple places to prevent accidental loss, on a laptop computer, desktop computer, and an external hard drive. Memory cards from the time-lapse cameras and Nikon camera were downloaded and cleared weekly. Data from the data loggers

were downloaded monthly. Weather was checked and downloaded weekly from the Missoula International Airport weather station.

Arthropod Collection

Entomological evidence is very important in forensic cases with human remains. Arthropods, especially insects, follow a predictable sequence when they colonize a deceased body (Haskell et al., 1997). Certain species of insects arrive to the body during different stages of decomposition and by identifying what species are present and what life stage they are in can help scientists estimate how long the individual has been deceased. Insects are one of the best indicators of postmortem interval. Forensically important insects have been studied and understood in detail in other geographic locations, however not much is known about the forensic entomology in Montana. Dudzik (2009) and Parson (2009) have suggested that the different types and quantities of insects found in Montana are one cause of the different decompositional patterns seen in this area.

For this research the insects were collected using multiple methods. Four pitfall traps were placed around each pig, one in each corner of the enclosure. The pitfall traps were created by placing a plastic funnel into red plastic Solo cups, and was left unbaited to prevent non-forensic insects from approaching the body to gain a better understanding of the insects that are specifically interested in decomposition and not just attracted by the bait substance. The trap was buried with the funnel opening exposed, and was covered with a plastic plate that was held down by rocks. The traps were emptied daily and if new types of insects were present they were collected. Sweep nets were used to manually collect flying insects. Insects and insect larva were also removed from the cadaver using soft tweezers and plastic spoons and placed in a container. When present, insects were photographed and recorded; the first time a new type of insect was

seen it was documented, collected, placed in labeled containers, and preserved for later analysis. Forensic anthropology student and entomologist, Marisha Richardson from the Emlen Evolutionary Biology Lab at the University of Montana and an EPT West certified invertebrate taxonomist from Rhithron Inc., analyzed and curated the entomological collection.

Data Analyses

Many qualitative methods were used throughout this research to document and compare the pigs deposited in October and December to one another in an effort to better understand how the environment affected each pig differently. The rate at which SS-1 and SS-2 went through the decay process was analyzed and was also compared to environmental factors such as minimum and maximum ambient temperatures and minimum and maximum relative humidity. Ambient temperature and internal temperatures of each pig were compared to the length and amount of bloat for each pig. The species of insects, succession, amount, location, and time in stasis have also been compared for SS-1 and SS-2.

This study was set up to follow previous studies by Parsons (2009) and Dudzik (2009) with the intention of creating a baseline dataset for western Montana. Their studies took place in the Lubrecht Experimental Forest located 25 miles east of Missoula at an elevation of 4,300 ft. To understand how the two different locations affected the rate and sequence of decomposition, the pig placed in Lubrecht on October 13, 2008 (LSS-2) was compared to this study's October 1, 2011 pig (SS-1) and the pig placed in Lubrecht November 20, 2008 (LSS-3) was compared to this study's December 2, 2011 pig (SS-2). Visual observations were compared along with the time each pig took in each decompositional stage.

Decomposition research has a history of being qualitative in nature and strictly based on researchers observations. In an effort to quantitatively evaluate decomposition, Megyesi et al. (2005) created a method of calculating accumulated degree days (ADD) to score visual assessments. Previous studied conducted at Lubrecht (Parson, 2009; Dudzik, 2009) suggested that using this method of time since death cannot be implemented in this specific geographic location as the resulting ADD does not give an accurate estimation of the postmortem interval. This study retested the accuracy of ADD in the Missoula Valley to see if the conclusions made by Dudzik are indeed true. Megyesi et al. (2005) use a modified version of Galloway et al.'s (1997, p141) 4 stages of decomposition 1) fresh, 2) early decomposition, 3) advanced decomposition, and 4) skeletonization. The description of the stages that were used to score decay are from Megeysi et al. (2005, p 621-622) and are separated into three different sections on the cadaver, decomposition for the head and neck (Table 2), decomposition for the trunk (Table 3), and decomposition for the limbs (Table 4).

Table 2: Descriptions of decomposition for the head and neck (from Megyesi et al., 2005, p 621)

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

Table 3: Descriptions of decomposition for the trunk (from Megyesi et al., 2005, p 621)

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

Table 4: Descriptions of decomposition for the limbs (from Megyesi et al., 2005, p 622)

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

For this study the 15th of every month was chosen to calculate ADD for each pig. Using descriptions from Megyesi et al. (2005), each section was scored and all three sections were added together to get the TBS. To calculate ADD a log-linear regression formula was used: ADD = $10^{(0.002*TBS*TBS+1.81)}$ ± 388.16. The standard deviation of ± 388.16 is used to get an 80% confidence interval. The ADD number is important because it represents the estimated number of degree days the individual has been dead. To calculate when the date of death occurred, the average ambient temperatures need to be collected from a local weather station. Working backwards through time from the day of recovery, or in this case the chosen date for each month,

the average daily temperatures are added together until ADD is reached. For this to be successful in locations were the ambient temperatures reaches below freezing, any day with an average temperature of 0°C is counted as 0 when adding up average daily temperatures. When the ADD is reached that is the estimated day of death, give or take the standard deviation. For this research projected ADD was calculated for SS-1 and SS-2 to see if the results follow expected patterns. Then ADD was compared to the actual death dates of SS-1 and SS-2. Given the previous results for decomposition in western Montana, it is expected that the estimated ADD will not be accurate, so to confirm or reject this statement these results have been compared to ADD calculations for LSS-2 and LSS-3.

CHAPTER 4: RESULTS

Results of this study indicate that Montana's unique environment and long winter season causes the slowing of decay and ultimately stasis in the decomposition process, in turn affecting the length of stages and how each carcass experiences each stage of decomposition. Tables 5 and 6 depict the rate and pattern in which each specimen went through in the decay process. Working with decomposition, visual observations have been and still are important to estimating the postmortem interval. However, an increasingly popular way of quantitatively estimating the postmortem interval is using the Megyesi et al. (2005) method of utilizing accumulated degree days (ADD). ADD has been calculated for SS-1 and SS-2 to examine if this is a reliable method for decomposition occurring in western Montana.

Table 5: Rate and pattern of decomposition for SS-1deposited October 1, 2011

Stages of Decomposition	Dates	Number of days
Fresh	10/1/11-10/2/11	1
Early Decomposition	10/2/11-10/28/11	26
Advanced Decomposition	10/28/11-11/14/11	17
Stasis	11/14/11-3/9/12	116
Advanced Decomposition	3/9/12-7/12/12	125
Mummification	7/12/12-10/1/12	80

Table 6: Rate and pattern of decomposition for SS-2 deposited December 2, 2011

Stages of Decomposition	Dates	Number of days
Fresh	12/2/11-12/9/11	7
Early Decomposition	12/10/11-12/29/11	19
Stasis	12/29/11-2/28/12	61
Early Decomposition	2/28/12-5/13/12	75
Advanced Decomposition	5/13/12-7/21/12	69
Mummification	7/21/12-12/2/12	134

Decompositional changes to SS-1

Fresh Stage SS-1

Time of death for SS-1 occurred at 2:35pm on October 1, 2011 marking the beginning of the fresh stage of decomposition. The adult female pig weighed approximately 180 pounds with a beginning abdominal measurement of 119cm. At the time of death the ambient temperature was 69°F (20.55°C) and the internal temperature of the carcass was 102.4°F (39.11°C). Final deposition occurred at 7:00pm and it was 62.2°F (16.78°C) at the research site. At the time of placement the internal temperature of the pig was 91.1° F (32.83°C) and the external temperature of the pig was 88.6°F (31.44°C). Lividity was observed at the time of deposition with purple coloring on the thorax, abdomen and all four legs (Figure 3).

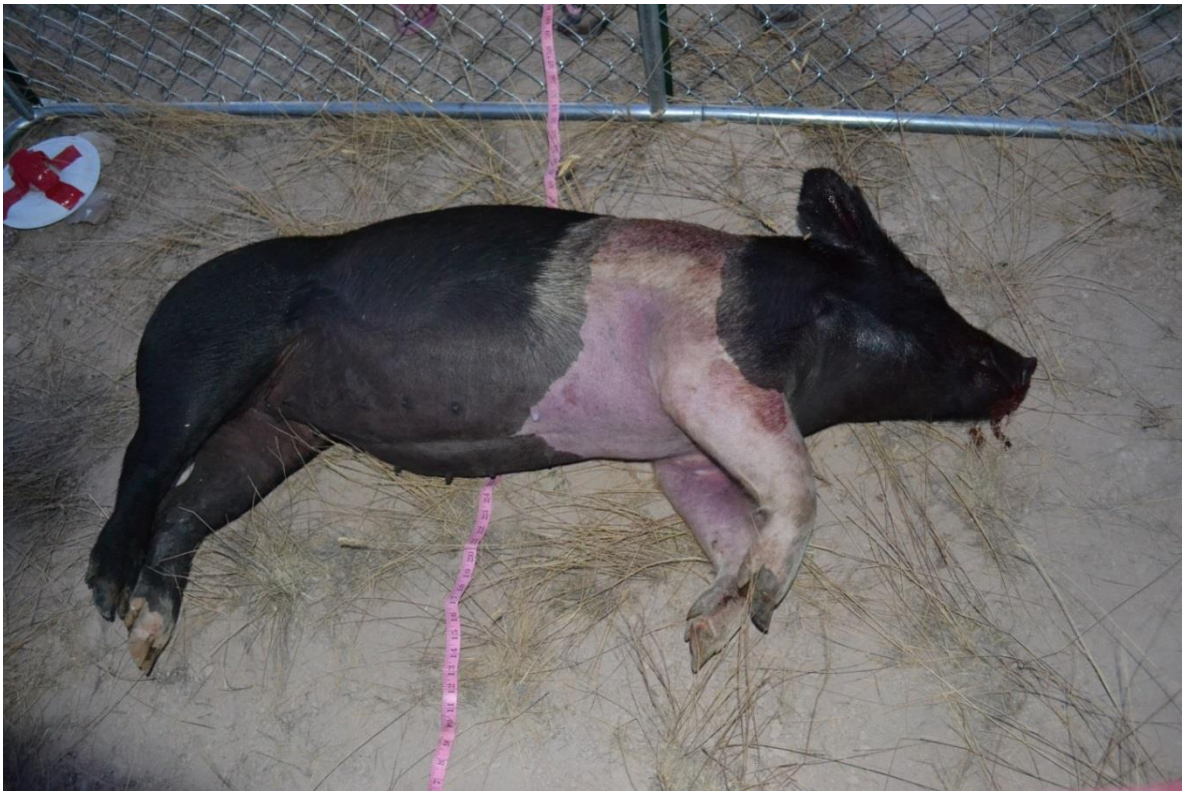

Figure 3: Day 1, 10/1/11, the fresh stage of decomposition

Early Decomposition Stage SS-1

The early stage of decomposition began day 2, 10/2/11 and two site visits occurred to document the early changes. At 9:15am the ambient temperature was 51.7°F (10.94°C), the external temperature of the remains was 58.8°F (14.89°C), and the internal temperature of the remains had dropped to 65.2°F (18.44°C) indicating that algor mortis was occurring. Putrefaction had begun; bloating had started causing the abdomen to feel taut, the front right leg lifted off the ground becoming parallel to the left front leg, and the abdominal measurement was 122cm. Thick bright red blood bubbled from the nose with an audible gurgling noise while a milky white fluid purged out of the anus. Internally autolysis had also begun with the manifestation of purple/pink marbling along the ventral surface, on the chest between the front legs, and the lower

abdomen between the back legs. Rigor mortis also set in making the front and back legs impossible to move. By 4:30pm that first day the ambient temperature increased to 82.0°F (27.78°C) and 75 to 100 flies gathered around the remains laying eggs along the left side of the neck towards the ground, in the right ear, and in the mouth. Rigor mortis relaxed to about 50% making some bending of the wrists possible. More fluid had purged out of the nose and orifices at the posterior end, the back right leg began to rise off the ground becoming parallel with the back left leg, and the abdomen measured at 124cm. The marbling on the ventral surface also became a darker purple color. The external temperature of the remains was 86.4°F (30.22°C) and the internal temperature was 84.0°F (28.89°C).

By day 3, 10/3/11, the ventral surface of the pig began to change colors to a mottled pink, purple, green, and blue. Putrefaction continued with an abdominal measurement of 132.5cm and the rectum began protruding out of the anus. Visible external signs of autolysis were present with the breaking down of the epidermis on the lower abdomen forming bullae specifically around the nipples, between the back legs, and in the leg creases. A faint odor of decomposition was also present. During the site visit on day 3, the ambient temperature was 61.9°F (16.61°C), the external temperature of the remains was 69.9°F (20.06°C), and the internal temperature of the remains was 77.5°F (25.28°C).

On day 4, 10/4/11, the ventral surface of the pig turned a blue grayish green color (Figure 4). Fresh red blood was still being purged out of the mouth. The fly eggs in the mouth hatched and small instar one maggots were visible along the lips and tongue. Bloat was still at 132.5cm with a little more of the rectum protruding than the day before. After day 4 the bloat slowly started to decrease. The ambient temperature at the time of the site visit was 57.2°F (14.00°C)

and had been raining most of the day. The external temperature of the pig was 59.3°F (15.17°C) and the internal temperature was 63.0°F (17.22°C).

Figure 4: Day 4, 10/4/11, early stage of decomposition

By day 5, 10/5/11, maggots hatched in the leg crease of the back left leg and in the orifices at the posterior end. The skin between the back legs was starting to turn a yellow/cream color and the color of the thoracic region was a grayish green/blue and stayed a greenish color until day 197, 4/15/12. By day 6, 10/6/11 maggots were located in the right eye, right ear, gunshot wound to the frontal bone, in the mouth, nose, on the dorsal side of the pig along the lumbar region, more in the anus and vagina, and the left hip along the ground. The tongue and roof of the mouth was a bright teal color which lasted for two days. The area of soft tissue

anatomically inferior to the vagina started to tear and oozed a mucus-like fluid, giving maggots an additional opening into the body (Figure 5).

Figure 5: Day 6, 10/6/1, the rectum protruding out of the anus and the start of the tear in the soft tissue on the posterior end of the carcass

By day 7, 10/7/11 the remains were no longer in rigor and the odor of decomposition became noticeably stronger. On day 8, 10/8/11 a new round of fly eggs were oviposited in the mouth and all along the dorsal side of the carcass and the ground; the eggs along the dorsal side stayed in stasis for 13 days hatching on day 21, 10/21/11. Also on the 8th day the skin on the lower abdomen began to slough off (Figure 6). Northern Carrion Beetles (*Thanatophilus lapponicus*) were the first beetles present on the remains and were seen eating maggots on day 13, 10/13/11. By day 14, 10/14/11, the maggot masses increased in size, however most of the

maggots were instar 2 and medium sized. The larger mass on the posterior end of the remains had begun to produce a thick tan foam and crackling and popping sounds were audible.

Figure 6: Day 8, 10/8/11 the skin was sloughing off and the maggot activity had increased

On day 14, 10/14/11the hair on the right side of the carcass visible changed looking wirier and started to stand up. Maggot masses again grew larger and more active on day 16, 10/16/11 and the odor changed, smelling like bad seafood and ammonia. The face also started to deflate and the skin started to desiccate making the mandible more prominent. When the ambient temperature would warm up or the sun come out flies would recongregate around the remains and lay eggs. Day 21, 10/21/11, eggs were deposited along the dorsal side of the remains and the ground. Day 23, 10/23/11, a large mass of eggs were deposited between the eyes and stayed in stasis for 23 days, 11/15/11 when snow covered the remains and ultimately washed

away the eggs. This multiple rounds of oviposition lead to many different stages and sizes of maggots feeding on the remains at one time (Figure 7).

Figure 7: Day 21, 10/21/1, different stages of maggots producing foam while feeding on the posterior end of the remains

Nearing the end of the early stage of decomposition on day 22, 10/22/11 the maggot masses reached their maximum size in respects to how far the masses extended out from the remains (Figure 8). The anterior teeth began to turn pink on day 23, 10/23/11, starting with the incisors and then the premolars. Also on that day a maxillary incisor fell out of the associated alveolus. The second incisor fell out on day 26, 10/26/11; both teeth remained on the ground under the mouth. By day 25, 10/25/11 the tongue became desiccated, shriveled, and turned black. The first of many Red- Legged Ham Beetles (*Necrobia rufipes*) was first observed on the

remains on day 27, 10/27/11. The early stage of decomposition lasted 26 days, 10/1/11 thru 10/28/11.

Figure 8: Day 22, 10/22/11, maggot masses

Advanced Decomposition Stage SS-1

On day 28, 10/28/11, the abdominal measurements revealed that the abdomen had started to deflate past the starting measurement indicating the remains had moved into the advanced stage of decomposition (Figure 9). A few different beetles were present during the advanced stages, on day 30, 10/30/11, a Burying beetle (*Nicrophorus*) was observed, and the first Giant Hairy Rove Beetle (*Creophilus maxillosus*) was seen on day 31, 10/31/11. On day 32, 11/1/11 large cream colored maggots were found under clumps of dirt 5 to 10 yards away from SS-1. The third tooth (premolar) loss occurred on day 33, 11/2/11 and the teeth increasing became pinker in

color staying pink until day 122, 1/30/12 (Figure 10). Also on day 33 the maggots located on the anterior region of the remains had slowed down and some had stopped moving all together, the larger maggots on the posterior end burrowed deeper inside the body and were able to generate enough heat to stay active for 12 days with ambient temperatures below freezing. The first snow occurred on day 36, 11/5/11 lightly covering the remains. Very little changed, however the larger maggots on the posterior end of the pig stayed active until day 45, 11/14/11 when it snowed again halting maggot activity.

Figure 9: Day 28, 10/28/11 First day of the advanced decomposition stage

The remains had been in active decomposition for 17 days before stasis in the decomposition occurred. Very little changes to the remains occurred until day 161, 3/9/12. Most days all maggot activity was halted, however when the ambient temperature reached around 40°F

(4.44°C) the larger maggots on the posterior end moved very slowly and on some days movement was not seen but maggots could be heard inside the posterior end of the pig. On day 56, 11/25/11, the exposed maggots on the anterior end of the pig turned a cinnamon brown color, an indicator that they were no longer alive. Rodent scavenging became an issue on day 74, 12/13/11 with gnawing on the inside of the left back leg and continued on throughout the winter. It was observed on day 81, 12/17/11 that the mandible was tilted toward the ground as a possible result of the left mandibular condyle slipping out of the temporomandibular joint.

Figure 10: Day 37, 11/6/11 pink teeth

Through the end of December 2011 and all of January and February 2012 there was snow off and on covering the carcass. It was cold, most days below freezing, and as a result no changes in decay occurred and no insect activity was seen. The last week in January 2012 a large snowstorm covered the research site and the remains in 20.3cm of snow making the site only

accessible by snowshoe. When the snow had cleared on parts of the anterior half of the remains on day 125, 2/2/12, small round patches of white, brown, and orange colored mold were visible along the right side of the neck and along the outside of the right front arm. The soft tissue of the thorax and abdomen felt squishy to the touch, like it was composed of gel under the outer layer of skin. At the end of February 2012 the skin on the head really started to dry out with the lips and roof of the mouth turning a yellowish tan color. On day 153, 3/1/12, a 0.5cm size drop of adipocere was observed on the right side of the neck and also a small yellow waxy drop along the crease above the tear on the posterior end which ultimately started dripping into the tear. Adipocere was observed on the remains 100 days until day 253, 6/9/12. The hair on the chin and also along the right side of the posterior end started turning white. The hoofs also started to dry out and flake.

On day 161, 3/9/12, the remains reentered advanced decomposition. The ambient temperature at the time of the site visit was 62.5°F (16.94°C) causing insects to be active, flies became interested and the Red-Legged Ham beetles and Northern Carrion beetles were observed along with two wasps. A thin film of white adipocere covered the right side of the neck and yellow waxy adipocere began to form on the dorsal side of the lumbar region of the carcass dripping to the ground. The remains had a more sweet musty smell to them and not as much of the decomposition smell as before. Other than the adipocere, there were minimal changes to the remains through March 2012, insects continued to be active with an increase in beetle activity, with Dung beetles (*Aphodius distinctus*) being seen for the first time. At the end of March 2012, the front legs started to constrict towards the body causing the arms to look smaller and curled in. On 182, 3/30/11, a large cream colored maggot was seen leaving the posterior end, most likely trying to migrate to pupate.

April 2012 the weather became warmer increasing the insect activity around the remains, more flies, Dung flies (*Scathophagidae*), Red-Legged Ham beetles, Northern Carrion beetles, Sap Beetles (*Nitidulidae)*, Dermesteds, hide beetles (*Dermestidae maculatus*), and Hister beetles (*Histeridae*). On day 193, 4/10/12 100's of flies were observed around the site sitting on the grass, along the handles of the plastic supply storage box, and on the cages; it is very possible this had occurred as a result of flies hatching from pupae casings. Beetle larvae were observed on the carcass on day 203, 4/20/12. The next day, 4/21/12, small maggots were producing a large amount of foam in the openings in the posterior end of the pig. By day 206, 4/23/12, there were 1000s of small to medium sized maggots feeding all lined up head down in the openings on the posterior end (Figure 11). Over the next couple of days more eggs were deposited and maggot masses formed again in the nose, mouth, and left hip crease. On 4/27/12, day 230, thick dark brown decomposition fluid and foam began to purge out of the posterior end measuring up to 40cm away from the remains and was giving off a strong ammonia odor. By the end of April bright green grass was growing around the remains.

Figure 11: Day 206, 4/23/12, Maggot mass on the posterior end of the remains along with Red-Legged Ham beetles and Dermestid beetles

The temperature warmed up in May 2012 and fly activity increases along with oviposition; another hatching of flies from pupae casings occurred on day 231, 5/18/12. Maggots of all different sizes were seen eating on the carcass, however not many changes occurred to the remains in May. Day 245, 6/1/2012, large maggots were still seen in the mouth and many were starting to burrow in the ground under the mouth to pupate (Figure 12). Day 252, 6/9/12, many pupae casings were seen around the pig, though maggots were still observed on the remains. On day 269, 6/26/12 the ambient temperature at the time of the site visit was 86.3°F (30.17°C) and the soft tissue was starting to dry out with the skin becoming more wrinkled. As of day 276, 7/2/12 maggots were no longer seen on the remains; however beetles and larvae were still active. By day 286, 7/12/12 the remains reached 100% mummification. The ambient temperatures were hot and the remains just continued to dry out and turn a darker brown. The last day data was

collected for SS-1 occurred on October 1, 2012, with the end result of mummification (Figure 13). Table 7 shows a summary of decomposition observed during site visits for SS-1.

Figure 12: Day 245, 6/1/2012, maggots observed migrating to pupate and decomposition fluid purging out of the posterior end

Figure 13: Day 365 10/1/12, last day of study for SS-1

Table 7: Summary of observations of decomposition during site visits for SS-1

Day	Stage of Decomposition	Ambient Temperature	Abdominal Measurement	External Temperature	Internal Temperature	Color
TOD	Fresh	69°F	119cm	-	102.4°F	Flesh colored
1	Fresh	62.2°F	119cm	88.6°F	91.1°F	Pink, purple
2	Early	82.0°F	124cm	86.4°F	84.0°F	Dark purple
3	Early	61.9°F	132.5cm	69.9°F	77.5°F	Pink, purple, green, blue
4	Early	57.2°F	132.5cm	59.3°F	63.0°F	Blue, gray, green
5	Early	53.0°F	131cm	55.0°F	60.9°F	Green, gray
28	Advanced	42.9°F	117cm	47.6°F	48.9°F	Green, Gray
45	Stasis	33.3°F	112.8cm	37.4°F	30.7°F	Green, Gray
161	Advanced	62.5°F	107.5cm	62.9°F	50.6°F	Black, green
286	Mummification	98.1°F	104.0cm	114.3°F	102.4°F	Tan, brown

Decompositional changes to SS-2

Fresh Stage SS-2

Time of death for SS-2 occurred at 11:15am on December 2, 2011 marking the beginning of the fresh stage of decomposition. The adult female pig weighted approximately 160 pounds with a beginning abdominal measurement of 109.5cm. At the time of death the ambient temperature was 55.0°F (12.78°C) and the internal temperature of the carcass was 102.3°F (39.06°C). Final deposition occurred at 5:00pm and it was 30.7°F (-0.72°C) at the research site. At the time of placement the internal temperature of the pig was 90.6° F (32.56°C) and the external temperature of the pig was 53.2°F (11.78°C). Lividity was observed at the time of deposition with light purple coloring on the thorax, and throat (Figure 14).

Figure 14: Day 1, 12/2/11, Fresh stage of decomposition. Lividity has started and the lines from the ropes that held the carcass in place during transport can be seen on the abdomen

Due to the cold weather this pig stayed in the fresh stage of decomposition for 7 days ending on 12/9/12. The ambient temperature at the time of the site visit on Day 2, 2/3/11, was 25.5°F (-3.61°C) and during that night the temperature had dropped to 15.0°F (-9.44°C), the pig had frost on the hair on the snout and along the right side. The internal temperature of the pig was 37.8°F (3.22°C), showing algor mortis was in action, and the external temperature of the pig was 27.7°F (-2.38°C). The legs had become stiff due to rigor mortis, however they were starting to feel hard to the touch and the freezing temperature also most likely affected the stiffness of the limbs. The pig was still pink with slight darker pink and light purple coloring from lividity. Her abdominal measurement actually decreased to 108cm and no blood had escaped the nose after deposition. There was no odor and no insect activity. That night it snowed at the site and covered the remains in approximately 4cm of snow and on day 3, 12/4/11 the ambient temperature at the site was 28.3°F (-2.06°C). The exposed skin on the ventral surface and on the throat was a mix of blotchy pink and red colors. The external temperature was 27.7°F (-2.39°C) and the internal temperature was 29.9°F (-1.17°C) and stayed in the 29°F range plus or minus 1°F for 87 days, finally increasing on 2/29/12. On day 4, 12/5/12 the ambient temperature at the time of the site visit was 18.3°F (-7.61°C) and the abdominal measurement was 107.0cm, staying within 1 centimeter for 95 days, finally exceeding 108cm on 3/9/12 .

Day 9, 12/10/11, the carcass slowly entered into the early decomposition stage. Autolysis of the red blood cells had occurred and purple marbling was observed on the posterior end of the remains, eventually occurring on the abdomen and on the inside of the front legs. Also the back right leg had risen 1cm above the left leg even though the abdominal bloat measurement was still 107.4cm; the back legs were touching the next day. This phenomenon occurred again on day 22, 12/23/11 and lasted for 6 days with the back legs touching on 12/29/12. Also during this time

frame there was an orange colored dust like substance observed on the lower abdomen and between the back legs lasting for 63 days from 12/15/11 to 2/16/12. Also the first evidence of rodent scavenging occurred on day 19, 12/20/11, with gnaw marks on the nose.

Day 28, 12/29/11 marked the beginning of the cold weather induced stasis in the decomposition process which lasted for 61 days ending on 2/28/12 (Figure 15). During this time very little changes occurred to the remains. Marbling still was observed with varying degrees of purple coloring. The remains were mostly pink to a darker red in places; however, on day 47, 1/17/12, the skin on the right side of the carcass turned an orange color. More rodent activity occurred on day 31, 1/1/12, with chewing on the posterior end anatomically inferior to the vagina (Figure 16) and again on day 60, 1/30/12, with chewing on the chest anatomically posterior to the right front leg (Figure 17).

Figure 15: Day 28, 12/29/11, the first day of stasis in the decomposition process

Figure 16: Day 35, 1/15/15, rodent scavenging on the posterior end

Figure 17: Day 60, 1/30/12, rodent gnawing on the chest occurring under the ice

The remains started to slowly begin to decompose again on day 89, 2/28/12, with the swelling of the back right leg. The next day, 2/29/12, bright red blood began to slowly leak out of the nose for 25 days finally stopping on 3/25/12. On day 93, 3/3/12, the tongue had a faint green tint to it and a faint whiff of decomposition could be detected. By day 99, 3/9/12, the ambient temperature warmed up attracting flies to the remains for the first time. The remains showed signs of bloating with the abdominal measurement finally being more than the starting measurement, the neck started to look swollen, and bright red blood began bubbling out of the nose. The teeth were visible for the first time and were tinted pink, they stayed pink colored until day 202, 6/20/12. Day 103, 3/13/12, the ventral surface was a very colorful mixture of dark purples, yellow, green, and blue. The area around the umbilicus began to bulge and the skin began to breakdown. Small round black patches of mold along the right side of the remains were first observed on 3/20/12. By day 114, 3/24/12 the colors on the ventral surface became darker and areas turned black. The left ventral side began to ooze a bloody decomposition fluid all along the ventral surface and ground (Figure 18). On day 115, 3/25/12, the rodent chewing had exposed an organ in the chest cavity which was starting to bloat.

Figure 18: Day 114, 3/24/12, the remains changing colors, fluid leaking along the ventral surface, and small black round patches of mold on the right side

Day 130, 4/9/12, the insect activity increased with flies being drawn to the mouth and the fluid along the ventral surface. Other insects that were seen during the early stage of decomposition were Northern Carrion beetles, Red-Legged Ham beetles, Hister beetles, Giant Hairy Rove beetles, beetle larvae, Dermestid beetles, Sap beetles, and Dung flies. The first oviposition occurred on day 136, 4/15/12, with eggs laid around the exposed organ on the chest and in the opening on the posterior end. On day 141, 4/20/12, the first maggots hatched in the opening on the posterior end. The abdominal measurement increased by 0.4cm causing the right front and back legs came off the ground parallel to the left front and back legs, staying this way until 5/13/12. Skin slippage was observed on the inside of the left front leg and between the back legs and new patches of orange colored mold appeared on the right side of the remains. A puddle of adipocere appeared under the mouth on day 145, 4/24/12, and was accompanied by strong

odor of decomposition and bad feces. The next day 4/25/12, maggot masses were seen in the posterior end, above the left hip, and in the left armpit. This day the maximum abdominal measurement of 123.2cm was reached (Figure 19).

The color of the remains changed on day 149, 4/28/12, the right side of the remains along the sternal end of the ribs turned a bright red and orange (Figure 20). Also that day a large hair mat started to form in the left armpit area. Adipocere was also seen dripping onto the ground just posterior to the left ear on 5/7/12. On day 159, 5/8/12, 500+ flies were on and flying around SS-2, most likely drawn to the extremely putrid decomposition and ammonia odors being given off by the remains.

Figure 19: Day 146, 4/25/12, the extent of the bloat and large egg masses between the back legs

Figure 20: Day 149, 4/28/12, orange and red coloring

Maggot activity was mostly internal and they never formed masses that extended out from the remains (Figure 21). By day 161, 5/10/12, a decomposition stain was formed around the remains and by day 163, 5/12/12 the remains began to deflate. On day 164, 5/13/12, the bloat was completed with the right front and back legs touching down to the ground marking the transition into the advanced decomposition stage. Including the time spent in stasis, the remains stayed in the early decomposition stage for 157 days.

Advanced Decomposition Stage SS-2

The advanced stage of decomposition started on day 164, 5/13/12 (Figure 22). The maggots continued to feed and grow larger while the remains became flatter and more desiccated. By day 168, 5/17/12, the abdomen sounded hollow when tapped on and the soft tissue on the neck was hard to the touch. Maggots were not seen but were clearly heard and the

odor was extremely putrid and smelled a little different than it had, more like rotting meat than the normal decomposition smell. Also on 5/17/12, a thick greenish grey substance was visible coming out of the posterior end of the remains.

By day 176, 5/25/12, the remains started to smell more sweet and musty like dried tissue. Beetle and beetle larvae activity increased exponentially on day 181, 5/30/12. A small mass of fly eggs were deposited in the right eye and also along the chin on day 189, 6/7/12. On day 192, 6/9/12, 100's of pupae casings were observed inside of the enclosure and the remains were becoming more flat (Figure 23). Beetles started eating holes in skin on the cheeks and the lips on day 204, 6/22/12. Still a few maggots were observed migrating way from the body to pupate on day 214, 7/2/12 and cheese skippers were seen jumping around after it had rained on day 222, 7/10/12. On day 224, 7/12/12, the skin along the back started to curl up as a result of the tissue drying; however under the drying skin the remains and the decomposition stain around the remains were still wet.

After day 233, 7/21/12, very little changed to the remains other than just drying and darkening of the soft tissue. Adipocere started to drip off the skin on the dorsal side in the lumbar region on day 242, 7/30/12, and the snout pulled up off the ground as a result of shrinking soft tissue on day 255, 8/12/12. The remains never reached the starting abdominal measurement, most likely as a result of the remains flattening out and then drying. The advanced stage of decomposition lasted for 69 days until the remains entered mummification on day 233, 7/21/12. Mummification lasted for 134 days concluding the last day of the study, December 2, 2012 (Figure 24). Table 8 shows a summary of decomposition for SS-2 observed during site visits and Figure 25 shows a summary of how each specimen moved through the stages of decomposition.

Figure 21: Day 160, 5/9/12, internal maggot mass at the posterior end

Figure 22: Day 164, 5/13/12, advanced stage of decomposition

Figure 23: Day192, 6/9/12, flattening of the remains

Figure 24: Day 365, 12/2/12, last day of the study.

Table 8: Summary of observations of decomposition during site visits for SS-1

Day	Stage of Decomposition	Ambient Temperature	Abdominal Measurement	External Temperature	Internal Temperature	Color
TOD	Fresh	55.0°F	109cm	-	102.3°F	Flesh colored
1	Fresh	30.8°F	109cm	53.2°F	90.6°F	Pink, purple
2	Fresh	25.5°F	108cm	27.7°F	37.8°F	Pink, purple
3	Fresh	28.3°F	107.3cm	27.7°F	29.9°F	Pink, red
4	Fresh	18.3°F	107.0cm	27.7°F	29.9°F	Pink, red
9	Early	26.4°F	107.4cm	27.0°F	29.5°F	Pink, red, purple
28	Stasis	40.0°F	107.4cm	35.0°F	28.4°F	Pink, red, purple
47	Stasis	26.8°F	108.1	27.1°F	28.7°F	Orange, pink, red, purple
89	Early	27.7°F	107.6cm	44.6°F	30.1°F	Black, red, orange, purple
146	Early	70.3°F	123.3cm	81.0°F	72.8°F	Black, red, orange
164	Advanced	77.0°F	118.5cm	93.8°F	97.0°F	Black, orange
233	Mummification	82.7°F	103.5cm	121.5°F	87.6°F	Tan, brown

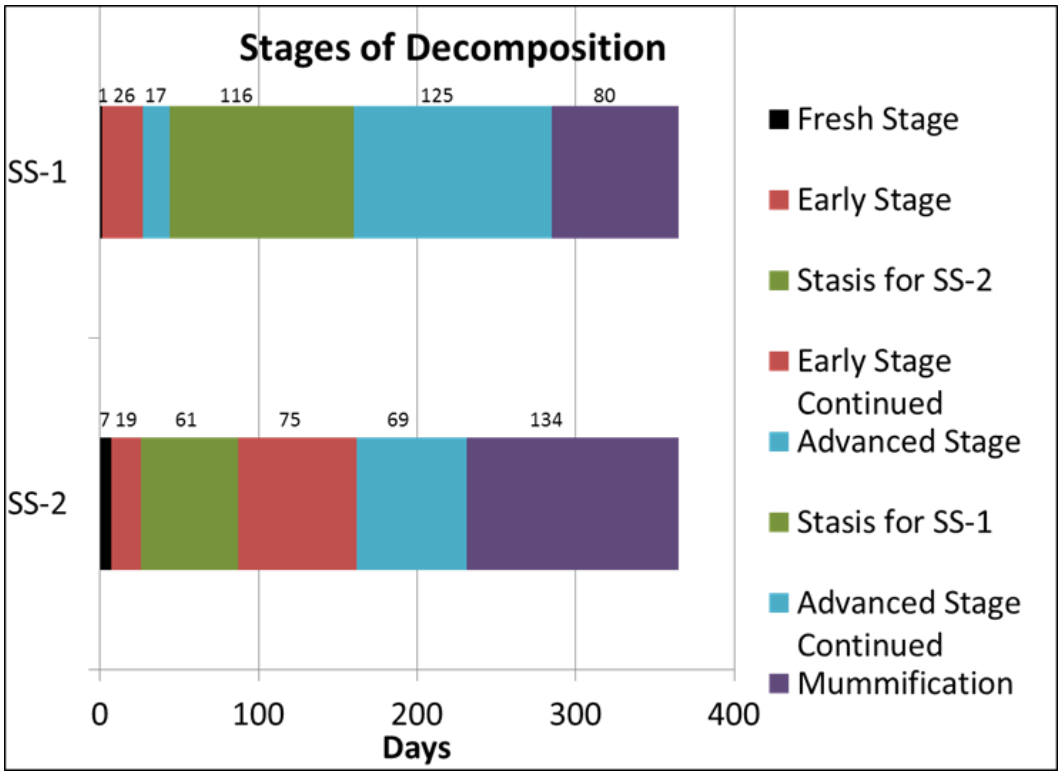

Figure 25: Summary table of the stages of decomposition for SS-1 and SS-2

Climatological Data

Weather data collection is a crucial aspect of this study. Ambient temperature and relative humidity were documented to try and understand how western Montana's specific weather affected how SS-1 and SS-2 moved through the stages of decomposition. Figures 26 and 27 show the minimum and maximum ambient temperature compared to the stages of decomposition for SS-1 and SS-2. By late October the temperature began to drop continuing through November. By December almost every day was around or below freezing which continued until the beginning of March when it slowly started to warm up into the 40s°F and 50s°F (4.44°C-10°C). By late June the temperature was becoming warm, and by July the high temperatures were in the 90s°F (32.2°C) with temperatures almost reaching a 100°F (37.78°C) in August. The warm weather persisted through September and finally dropped back into the 50s

and 60s (10°C- 15.56°C) in October with the lows in the 20s and 30s (-6.67°C to -1.11°C). A unique aspect of western Montana's ambient temperature is how large the distance can be between the daily high and low. In the winter the temperature range can be between 5°F to 35°F between the high and the low, in the summer the range between high and low temperatures can be from 25° to 49°F. As a result of this it is common in July and especially August for the high during the day to be in the 90s°F (32.22°C) and during the night drop into the 50s°F (10°C). Another factor unique to western Montana is how fast the temperature can change throughout the day from one minute to the next.

Relative humidity also plays an important role in the rate and pattern of decomposition, and in western Montana it has an interesting relationship with the ambient temperature. Like the ambient temperature, humidity often changes drastically throughout the day with large differences between the daily high percent and low percent relative humidity (Figures 27 and 28). October 12, 2012 is a good example of the large range in humidity, the lowest point was 14% relative humidity and the highest that same day reached 92% relative humidity. Throughout the year the average relative humidity has an inverse relationship with the average ambient temperature (Figures 29 and 30). In the fall starting at the end of September, the average ambient temperature starts to decrease while the average relative humidity starts to increase. Late October, through the winter to the beginning of April the average relative humidity is high while the average ambient temperature stays low. During the spring months of April and May, the two cross and fluctuate from high to low. The summer from the end of June through September the average ambient temperature rises while the average relative humidity decreases.

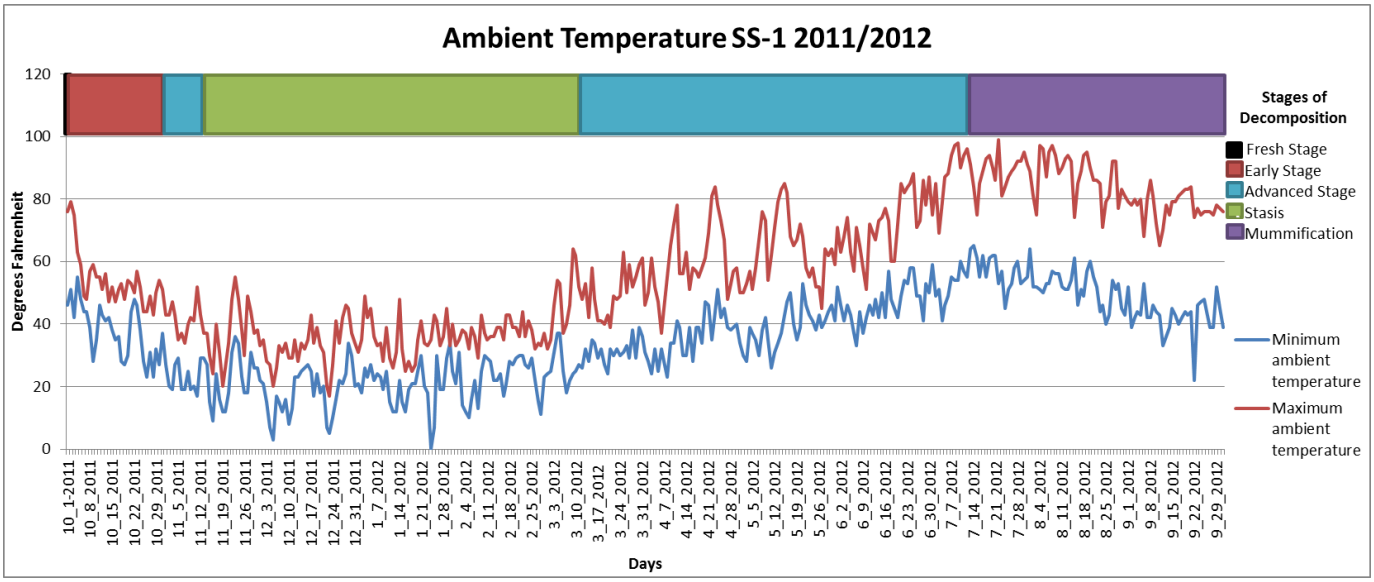

Figure 26: A comparison of maximum and minimum ambient temperatures vs. the stages of decomposition for SS-1, 2011/2012

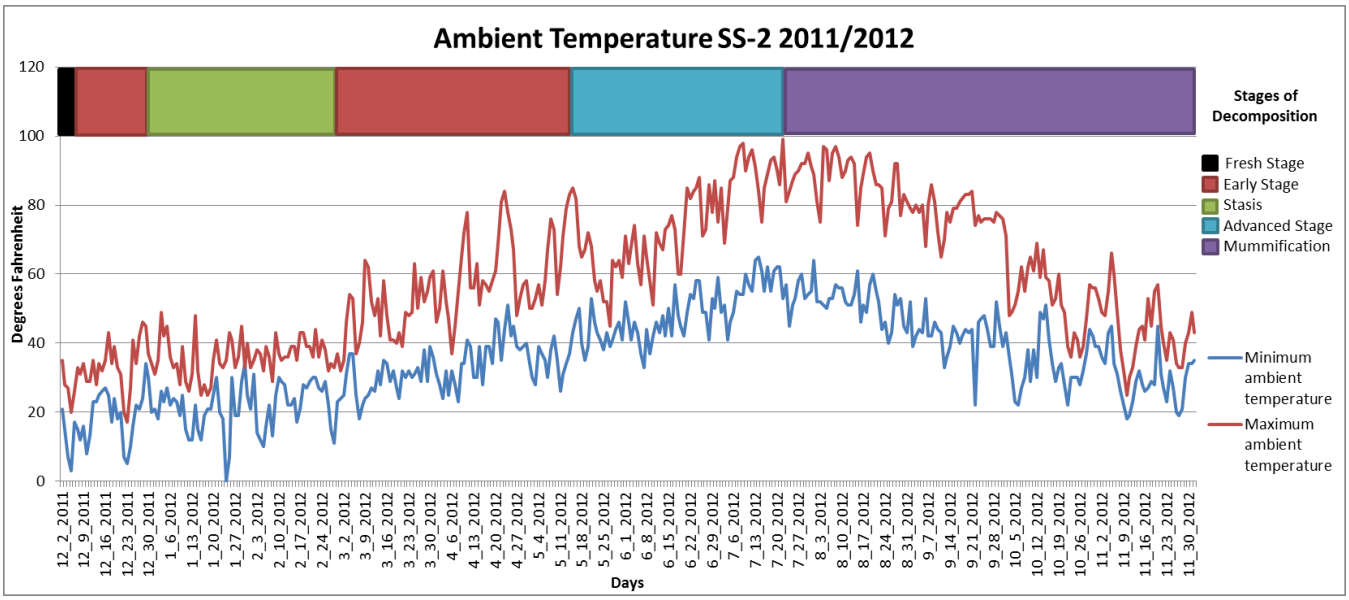

Figure 27: A comparison of maximum and minimum ambient temperatures vs. the stages of decomposition for SS-2, 2011/2012

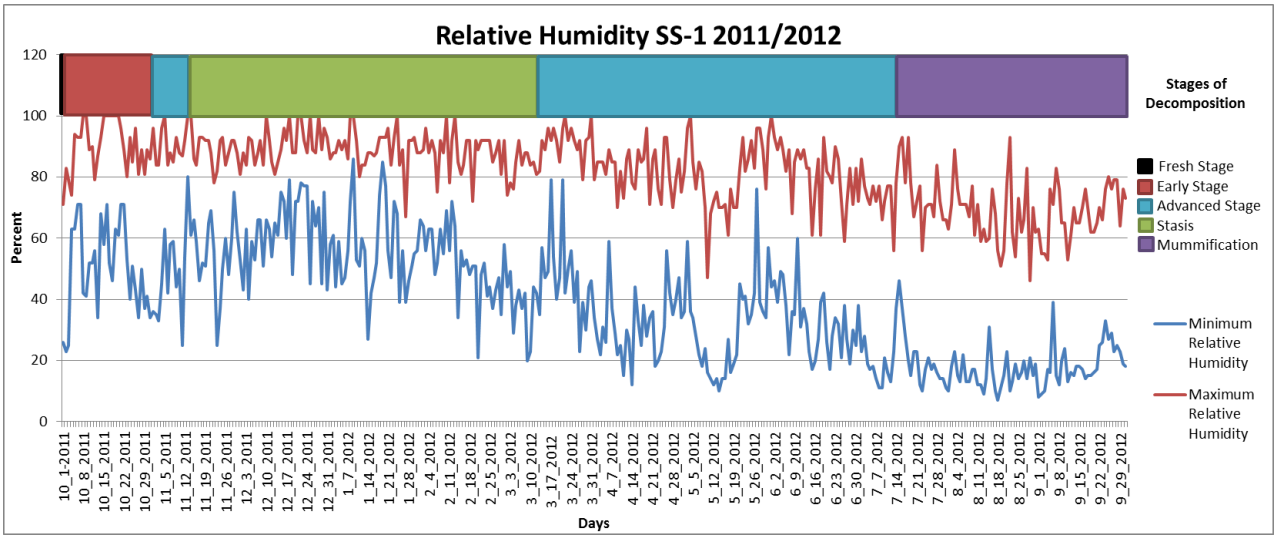

Figure 28: Minimum and maximum relative humidity vs. the stages of decomposition for SS-1, 2011/2012

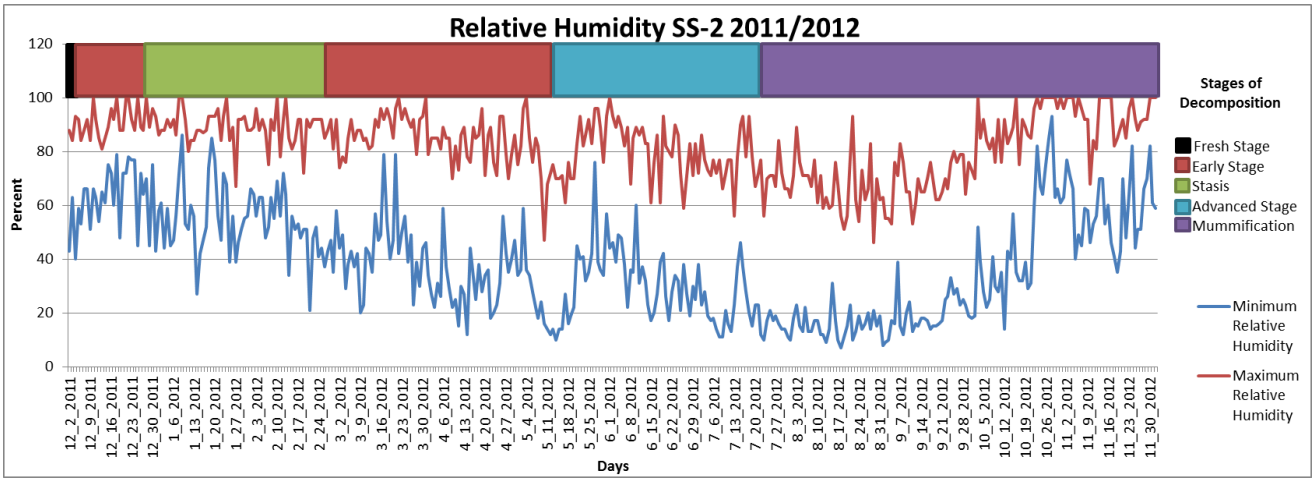

Figure 29: Minimum and maximum relative humidity vs. the stages of decomposition for SS-2, 2011/2012

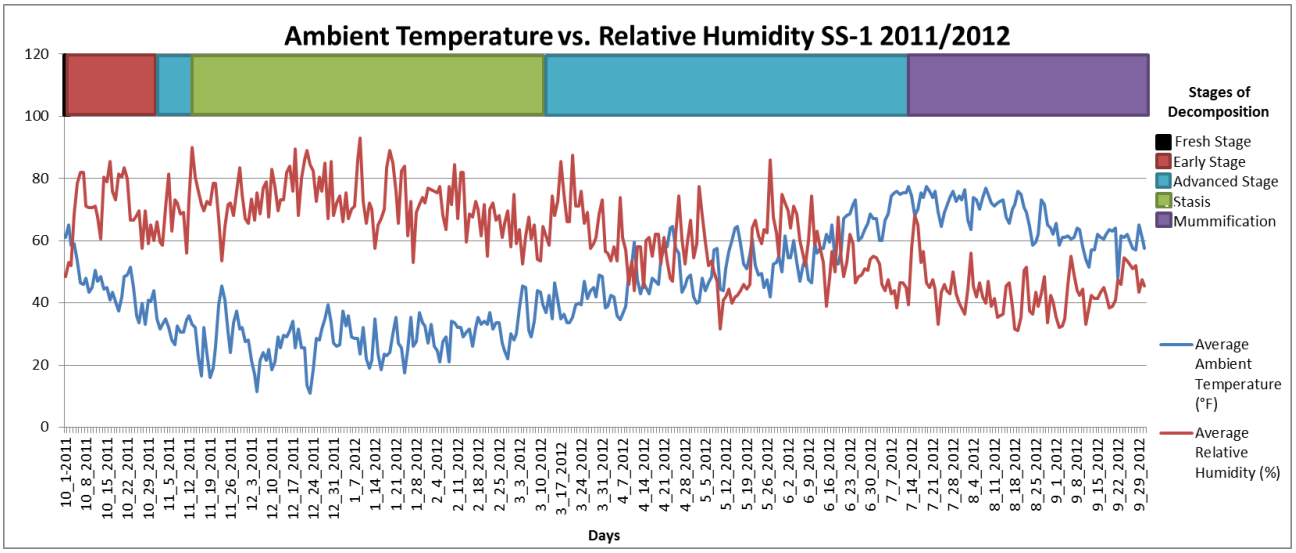

Figure 30: Average ambient temperature compared to average relative humidity vs. the stages of decomposition for SS-1, 2011/2012

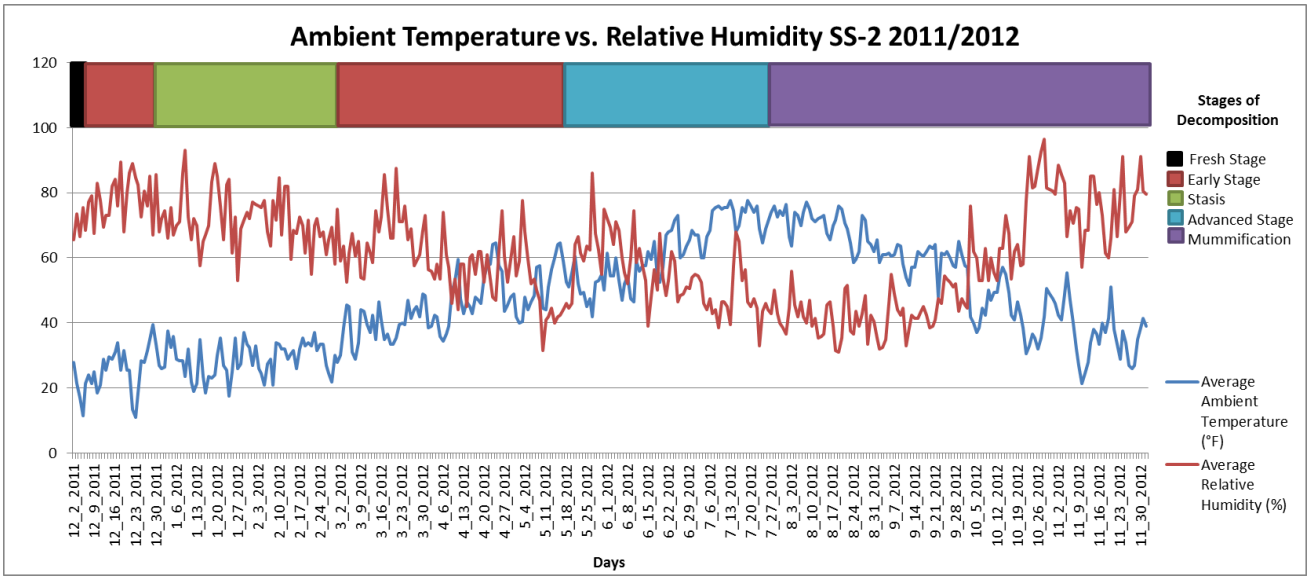

Figure 31: Average ambient temperature compared to average relative humidity vs. the stages of decomposition for SS-2, 2011/2012

Testing the Accumulated Degree Days Method

Accumulated Degree Days for SS-1

To further investigate if using the method of accumulated degree days is an accurate method for estimating the postmortem interval in western Montana, the Megyesi et al. (1995) method was applied to SS-1. The 15th day of each month was chosen to be the "discovery date" and was used to compare the estimated day of death to the actual day of death for 10/15/11, 11/15/11, 12/15/11, 1/15/12, 2/15/12, 3/15/13, 4/15/12, 5/15/12, 6/15/12, 7/15/12, 8/15/12, 9/15/12. For each discovery day the observational scores were added together to obtain the TBS which was then placed in Megyesi and colleagues' equation ADD = $10^{(0.002*TBS*TBS+1.81)}$ ± 388.16 to determine the estimated ADD (Table 9-32). ADD was used to obtain the estimated day of death. The difference was taken from the estimated day of death and the discovery date to find the estimated PMI. Then the estimated PMI was subtracted from the actual PMI to see how accurate the method of using ADD was when predicting the actual PMI.

Table 9: SS-1 Calculation of TBS for 10/15/11, day 15

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Some bloating of the neck and face	5
Trunk	Early Decomposition	Bloating with green discoloration	4
Limbs	Early Decomposition	Gray to green discoloration	3
TBS			**12**

Table 10: SS-1 Calculation of ADD for 10/15/11, day 15, TBS=12

Estimated ADD **Estimation of date of death** **Estimated PMI**	125.31degree days 10/13/11-10/14/11 1-2 days
Actual ADD **Actual date of death** **Actual PMI**	761.5 degree days 10/1/11 15 days
Error in the calculation of PMI	13-14 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0 to 513.47 degree days 10/5/11-10/15/11 0-10 days

Table 11: SS-1 Calculation of TBS for 11/15/11, day 46

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Brown to black discoloration of the flesh	6
Trunk	Early Decomposition	Post bloating with discoloration changing from green to black	5
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**15**

Table 12: SS-1 Calculation of ADD for 11/15/11, day 46, TBS= 15

Estimated ADD **Estimation of date of death** **Estimated PMI**	181.97 degree days 11/3/11-11/4/11 12-13 days
Actual ADD **Actual date of death** **Actual PMI**	1167 degree days 10/1/11 46 days
Error in the calculation of PMI	33-34 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0 to 570.13 degree days 10/24/11-11/15/11 0-23 days

Table 13: SS-1 Calculation of TBS for 12/15/11, day 76

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Caving in of the flesh and tissue of the eyes and throat	7
Trunk	Early Decomposition	Discoloration from green to black	5
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**16**

Table 14: SS-1 Calculation of ADD for 12/15/12, day 76, TBS= 16

Estimated ADD **Estimation of date of death** **Estimated PMI**	209.89 degree days 11/13/11-11/22/11 24-33 days
Actual ADD **Actual date of death** **Actual PMI**	1864 degree days 10/1/11 76 days
Error in the calculation of PMI	43-52 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0 to 598.05 degree days 10/29/11-12/15/11 0-48 days

Table 15: SS-1 Calculation of TBS for 1/15/12, day 107

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Caving in of the flesh and tissue of the eyes and throat	7
Trunk	Early Decomposition	Discoloration from green to black	5
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**16**

Table 16: SS-1 Calculation of ADD for 1/15/12, day 107, TBS= 16

Estimated ADD **Estimation of date of death** **Estimated PMI**	209.89 degree days 12/29/11-12/30/11 17-18 days
Actual ADD **Actual date of death** **Actual PMI**	2147 degree days 10/1/11 107 days
Error in the calculation of PMI	89-90 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0 to 598.05 degree days 11/8/11-1/15/12 0-69 days

Table 17: SS-1 Calculation of TBS for 2/15/12, day 138

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Caving in of the flesh and tissue of the eyes and throat	7
Trunk	Early Decomposition	Discoloration from green to black	5
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**16**

Table 18: SS-1 Calculation of ADD for 2/15/12, day 138, TBS= 16

Estimated ADD **Estimation of date of death** **Estimated PMI**	209.89 degree days 1/29/12 18 days
Actual ADD **Actual date of death** **Actual PMI**	2421.5 degree days 10/1/11 138 days
Error in the calculation of PMI	120 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-598.05 degree days 11/28/11-2/15/12 0-80 days

Table 19: SS-1 Calculation of TBS for 3/15/12, day 167

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Caving in of the flesh and tissue of the eyes and throat	7
Trunk	Early Decomposition	Discoloration from green to black	5
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**16**

Table 20: SS-1 Calculation of ADD for 3/15/12, day 167, TBS= 16

Estimated ADD **Estimation of date of death** **Estimated PMI**	209.89 degree days 3/1/12-3/2/12 14-15 days
Actual ADD **Actual date of death** **Actual PMI**	3113 degree days 10/1/11 167 days
Error in the calculation of PMI	152-153 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-598.05 degree days 2-21/12-3/15/12 0-24 days

Table 21: SS-1 Calculation of TBS for 4/15/12, day 198

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Caving in of the flesh and tissue of the eyes and throat	7
Trunk	Advanced Decomposition	Caving of the abdominal cavity	6
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**17**

Table 22: SS-1 Calculation of ADD for 4/15/12, day 198, TBS=17

Estimated ADD **Estimation of date of death** **Estimated PMI**	244.34 degree days 4/11/12 5 days
Actual ADD **Actual date of death** **Actual PMI**	4415 degree days 10/1/11 198 days
Error in the calculation of PMI	193 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-632.5 degree days 4/1/12-4/15/12 0-15 days

Table 23: SS-1 Calculation of TBS for 5/15/12, day 228

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Moist decomposition	8
Trunk	Advanced Decomposition	Moist decomposition	7
Limbs	Early Decomposition	Brown to black discoloration	5
TBS			**20**

Table 24: SS-1 Calculation of ADD for 5/15/12, day 228, TBS=20

Estimated ADD **Estimation of date of death** **Estimated PMI**	407.38 degree days 5/8/12-5/9/12 7-8 days
Actual ADD **Actual date of death** **Actual PMI**	5910.5 degree days 10/1/11 228 days
Error in the calculation of PMI	220-221 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	19.22-795.54 4/30/12-5/15/12 0-16 days

Table 25: SS-1 Calculation of TBS for 6/15/12, day 259

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Moist decomposition	8
Trunk	Advanced Decomposition	Moist decomposition	7
Limbs	Early Decomposition	Brown to black discoloration	5
TBS			**20**

Table 26: SS-1 Calculation of ADD for 6/15/12, day 259, TBS=20

Estimated ADD **Estimation of date of death** **Estimated PMI**	407.38 degree days 6/8/12-6/9/12 7-8 days
Actual ADD **Actual date of death** **Actual PMI**	7572 degree days 10/1/11 259 days
Error in the calculation of PMI	251-252 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	19.22-797.54 degree days 6/2/12-6/15/12 0-16 days

Table 27: SS-1 Calculation of TBS for 7/15/12, day 289

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 28: SS-1 Calculation of ADD for 7/15/12, day 289, TBS=24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 7/3/12 13 days
Actual ADD **Actual date of death** **Actual PMI**	9587 degree days 10/1/12 289 days
Error in the calculation of PMI	276 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 6/27/12-7/9/12 7-18 days

Table 29: SS-1 Calculation of TBS for 8/15/12, day 320

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 30: SS-1 Calculation of ADD for 8/15/12, day 320, TBS=24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 8/2/12-8/3/12 13-14 days
Actual ADD **Actual date of death** **Actual PMI**	11806.5 degree days 10/1/11 320 days
Error in the calculation of PMI	306-307 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 7/28/12-8/8/12 8-19 days

Table 31: SS-1 Calculation of TBS for 9/15/12, day 351

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 32: SS-1 Calculation of ADD for 9/15/12, day 351, TBS=24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 8/31/12-9/1/12 15-16 days
Actual ADD **Actual date of death** **Actual PMI**	13785 degree days 10/1/11 351 days
Error in the calculation of PMI	335-336 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 8/25/12-9/7/12 9-22 days

The method of calculating an estimated time since death (TSD) using ADD underestimated the actual TSD throughout the whole study for SS-1. The first calculation for 10/15/11 underestimated the actual PMI by 13-14 days. Overtime the days underestimated got increasingly larger and ultimately by the end of the study the calculation for 9/15/12 underestimated the estimated PMI from the actual PMI by 335-336 days. TBS also increased slowly and as a result of the cold weather and stasis that occurred, the remains scored the same TBS for many months. The calculations for 12/15/12, 1/15/12, and 2/15/12 all scored a TBS of 16. The same TBS occurred again for 5/15/12 and 6/15/12 with a TBS of 20. Finally as a consequence of the warmer weather and the remains fully mummifying, the maximum TBS of 24 was reached on 7/15/12 staying 24 until the last calculation on 9/15/12. The summary Table 32 shows the error in the estimated PMI increasing throughout the study along with the duplication of total body scores.

Table 33: Summary table of ADD and PMI calculations for SS-1

Date of Calculation	TBS	Estimated ADD	Actual ADD	Estimated PMI (days)	Actual PMI (days)	Estimated Date of Death	Actual Date of Death	Error (PMI)
10/15/11	12	125.31	761.5	1-2	15	10/13/11 - 10/14/11	10/1/11	13-14 days underestimated
11/15/11	15	181.97	1167	12-13	46	11/3/11-11/4/11	10/1/11	33-34 days underestimated
12/15/11	16	209.89	1864	24-33	76	11/13/11-11/22/11	10/1/11	43-52 days underestimated
1/15/12	16	209.89	2147	17-18	107	12/29/11-12/30/11	10/1/11	89-90 days underestimated
2/15/12	16	209.89	2421.5	18	138	1/29/12	10/1/11	120 days underestimated
3/15/12	16	209.89	3113	14-15	167	3/1/12-3/2/12	10/1/11	142-142 days underestimated
4/15/12	17	244.34	4415	5	198	4/11/12	10/1/11	193 days underestimated
5/15/12	20	407.38	5910.5	7-8	228	5/8/12-5/9/12	10/1/11	220-221 days underestimated
6/15/12	20	407.38	7572	7-8	259	6/8/12-6/9/12	10/1/11	251-252 days underestimated
7/15/12	24	916.22	9587	13	289	7/3/12	10/1/11	276 days underestimated
8/15/12	24	916.22	11806.5	13-14	320	8/2/12-8/3/12	10/1/11	306-307 days underestimated
9/15/12	24	916.22	13785	15-16	351	8/31/12-9/1/12	10/1/11	335-336 days underestimated

Accumulated Degree Days for SS-2

The Megyesi et al. (1995) method of ADD gave inaccurate estimations of the day of death for SS-1. The next question to be investigated is if stasis occurs in a different stage of the decay process does that have an effect on the accuracy of estimating ADD? The method of ADD will be applied to SS-2 to see if a different rate of decomposition gives different results on how accurate the method is for western Montana. The 15th day of each month was again chosen to compare the estimated day of death to the actual day of death for 12/15/11, 1/15/12, 2/15/12, 3/15/13, 4/15/12, 5/15/12, 6/15/12, 7/15/12, 8/15/12, 9/15/12/,10/15/12, and 11/15/12 (Tables 34-57).

Table 34: SS-2 Calculation of TBS for 12/15/11, day 14

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Pink-white appearance	2
Trunk	Early Decomposition	Pink-white appearance and marbling present	2
Limbs	Early Decomposition	Pink-white appearance	2
TBS			**6**

Table 35: SS-2 Calculation of ADD for 12/15/11, day 14, TBS= 6

Estimated ADD **Estimation of date of death** **Estimated PMI**	76.21 degree days 11/27/11 19 days
Actual ADD **Actual date of death** **Actual PMI**	0 degree day 12/2/11 14 days
Error in the calculation of PMI	5 days overestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0 to 464.37 degree days 10/31/11-12/15/11 0-46 days

Table 36: SS-2 Calculation of TBS for 1/15/12, day 45

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Pink-white appearance	2
Trunk	Early Decomposition	Pink-white appearance and marbling present	2
Limbs	Early Decomposition	Pink-white appearance	2
TBS			**6**

Table 37: SS-2 Calculation of ADD for 1/15/12, day 45, TBS= 6

Estimated ADD **Estimation of date of death** **Estimated PMI**	76.21 degree days 1/5/12 11 days
Actual ADD **Actual date of death** **Actual PMI**	283 degree days 12/2/11 45 days
Error in the calculation of PMI	34 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-464.37 degree days 11/22/11-1/15/12 0-55 days

Table 38: SS-2 Calculation of TBS for 2/15/12, day 76

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Pink-white appearance	2
Trunk	Early Decomposition	Pink-white appearance and marbling present	2
Limbs	Early Decomposition	Pink-white appearance	2
TBS			**6**

Table 39: SS-2 Calculation of ADD for 2/15/12, day 76, TBS= 6

Estimated ADD **Estimation of date of death** **Estimated PMI**	76.21degree days 2/9/12 7 days
Actual ADD **Actual date of death** **Actual PMI**	557.5 degree days 12/2/11 76 days
Error in the calculation of PMI	69 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-464.37 degree days 12/30/11-2/15/12 0-106 days

Table 40: SS-2 Calculation of TBS for 3/15/12, day 105

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Discoloration, drying of nose, ears, and lips	4
Trunk	Early Decomposition	Gray discoloration	3
Limbs	Early Decomposition	Gray discoloration, marbling	3
TBS			**10**

Table 41: SS-2 Calculation of ADD for 3/15/12, day 105, TBS= 10

Estimated ADD **Estimation of date of death** **Estimated PMI**	102.33 degree days 3/13/12-3/14/12 2-3 days
Actual ADD **Actual date of death** **Actual PMI**	1248 degree days 12/2/11 105 days
Error in the calculation of PMI	102-103 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-490.49 degree days 2/25/12-3/15/12 0-20 days

Table 42: SS-2 Calculation of TBS for 4/15/12, day 136

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Discoloration, drying of nose, ears, and lips	4
Trunk	Early Decomposition	Bloating	4
Limbs	Early Decomposition	Discoloration and /or brownish shades	4
TBS			**12**

Table 43: SS-2 Calculation of ADD for 4/15/12, day 136, TBS= 12

Estimated ADD **Estimation of date of death** **Estimated PMI**	125.31 degree days 4/13/12-4/14/12 2-3 days
Actual ADD **Actual date of death** **Actual PMI**	2551 degree days 12/2/11 136 days
Error in the calculation of PMI	133-134 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-513.47 degree days 4/5/12-4/15/12 0-11 days

Table 44: SS-2 Calculation of TBS for 5/15/12, day 166

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Early Decomposition	Discoloration, drying of nose, ears, and lips	4
Trunk	Early Decomposition	Post bloating, discoloration changing from green to black	5
Limbs	Early Decomposition	Discoloration and/or brownish shades	4
TBS			**13**

Table 45: SS-2 Calculation of ADD for 5/15/12, day 166, TBS= 13

Estimated ADD **Estimation of date of death** **Estimated PMI**	140.60 degree days 5/13/12-5/14/12 2-3 days
Actual ADD **Actual date of death** **Actual PMI**	4076.5 degree days 12/2/11 166 days
Error in the calculation of ADD	163-164 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-528.76 degree days 5/6/12-5/15/12 0-10 days

Table 46: SS-2 Calculation of TBS for 6/15/12, day 197

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Caving in of the flesh and tissues of the eyes and throat	7
Trunk	Advanced Decomposition	Moist decomposition	7
Limbs	Early Decomposition	Brown to black discoloration, skin having a leathery appearance	5
TBS			**19**

Table 47: SS-2 Calculation of ADD for 6/15/12, day 197, TBS= 19

Estimated ADD **Estimation of date of death** **Estimated PMI**	340.41 degree days 6/9/12-6/10/12 6-7 days
Actual ADD **Actual date of death** **Actual PMI**	5738 degree days 12/2/11 197 days
Error in the calculation of PMI	190-191 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	0-728.57 degree days 6/3/12-6/15/12 0-13 days

Table 48: SS-2 Calculation of TBS for 7/15/12, day 227

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Moist decomposition	8
Trunk	Advanced Decomposition	Moist decomposition	7
Limbs	Advanced Decomposition	Moist decomposition	6
TBS			**21**

Table 49: SS-2 Calculation of ADD for 7/15/12, day 227, TBS= 21

Estimated ADD **Estimation of date of death** **Estimated PMI**	492.04 degree days 7/9/12-7/10/12 6-7 days
Actual ADD **Actual date of death** **Actual PMI**	7753 degree days 12/2/11 227 days
Error in the calculation of PMI	220-221 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	103.88-880.2 degree days 7/3/12-7/14/12 2-13 days

Table 50: SS-2 Calculation of TBS for 8/15/12, day 258

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 51: SS-2 Calculation of ADD for 8/15/12, day 258, TBS= 24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 8/3/12 13 days
Actual ADD **Actual date of death** **Actual PMI**	9972 degree days 12/2/11 258 days
Error in the calculation of PMI	245 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 7/28/12-8/8/12 8-19 days

Table 52: SS-2 Calculation of TBS for 9/15/12, day 289

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 53: SS-2 Calculation of ADD for 9/15/12, day 289, TBS= 24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 8/31/12-9/1/12 15-16 days
Actual ADD **Actual date of death** **Actual PMI**	11950.5 degree days 12/2/11 289 days
Error in the calculation of PMI	273-274 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 8/25/12-9/7/12 9-22 days

Table 54: SS-2 Calculation of TBS for 10/15/12, day 319

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 55: SS-2 Calculation of ADD for 10/15/12, day 319, TBS= 24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 9/27/12-9/28/12 18-19 days
Actual ADD **Actual date of death** **Actual PMI**	13578.5 degree days 12/2/11 319 days
Error in the calculation of PMI	300-301 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 9/22/12-10/5/12 11-24 days

Table 56: SS-2 Calculation of TBS for 11/15/12, day 350

Body Region	Stage of Decomposition	Description	Score
Head and Neck	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	9
Trunk	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	8
Limbs	Advanced Decomposition	Mummification with bone exposure less than half of area being scored	7
TBS			**24**

Table 57: SS-2 Calculation of ADD for 11/15/12, day 350, TBS= 24

Estimated ADD **Estimation of date of death** **Estimated PMI**	916.22 degree days 10/18/12-10/19/12 28-29 days
Actual ADD **Actual date of death** **Actual PMI**	14598 degree days 12/2/11 350 days
Error in the calculation of PMI	320-321 days underestimated
ADD range **(80% confidence interval)** **Estimated PMI range (80% CI)**	528.06-1304.38 degree days 10/10/12-10/30/12 17-37 days

Using the Megyesi et al. (2005) method of calculating ADD for SS-2 began differently than the calculations for SS-1. The first calculation on 12/15/11 actually overestimated the PMI by 5 days as a result of the below freezing temperatures giving an actual ADD of 0 degree days. The next calculation on 1/15/12 marked the beginning of underestimating the actual PMI. By the last calculation on 11/15/12 the estimated ADD underestimated the actual PMI by 320-321 days. TBS also increased slowly for SS-2. As a result of the remains freezing upon decomposition the TBS stayed 6 for the calculations on 12/15/11, 1/15/12, and 2/15/12. By 7/15/12 full mummification was reached giving a TBS of 24 degree days until the last calculation on 11/15/12. The summary Table 58 shows the error in the estimated PMI compared to the actual PMI. Figure 32 shows the relationship between TBD and ADD for each specimen and how they compare to each other.

Table 58: Summary table of ADD and PMI calculations for SS-2

Date of Calculation	TBS	Estimated ADD	Actual ADD	Estimated PMI (days)	Actual PMI (days)	Estimated Date of Death	Actual Date of Death	Error
12/15/11	6	76.21	0	19	14	11/27/11	12/2/11	5 days overestimated
1/15/12	6	76.21	283	11	45	1/5/12	12/2/11	34 days underestimated
2/15/12	6	76.21	557.5	7	76	2/9/12	12/2/11	69 days underestimated
3/15/12	10	102.33	1248	2-3	105	3/13/12-3/14/12	12/2/11	102-103 days underestimated
4/15/12	12	125.31	2551	2-3	136	4/13/12-4/14/12	12/2/11	133-134 days underestimated
5/15/12	13	140.60	4076.5	2-3	166	5/13/12-5/14/12	12/2/11	163-164 days underestimated
6/15/12	19	340.41	5738	6-7	197	6/9/12-6/10/12	12/2/11	190-191 days underestimated
7/15/12	21	492.04	7753	6-7	227	7/9/12-7/10/12	12/2/11	220-221 days underestimated
8/15/12	24	916.22	9972	13	258	8/3/12	12/2/11	245 days underestimated
9/15/12	24	916.22	11950	15-16	289	8/31/12-9/1/12	12/2/11	273-274 days underestimated
10/15/12	24	916.22	13578.5	18-19	319	9/27/12-9/28/12	12/2/11	300-301 days underestimated
11/15/12	24	916.22	14598	28-29	350	10/18/12-10/19/12	12/2/11	320-321 days underestimated

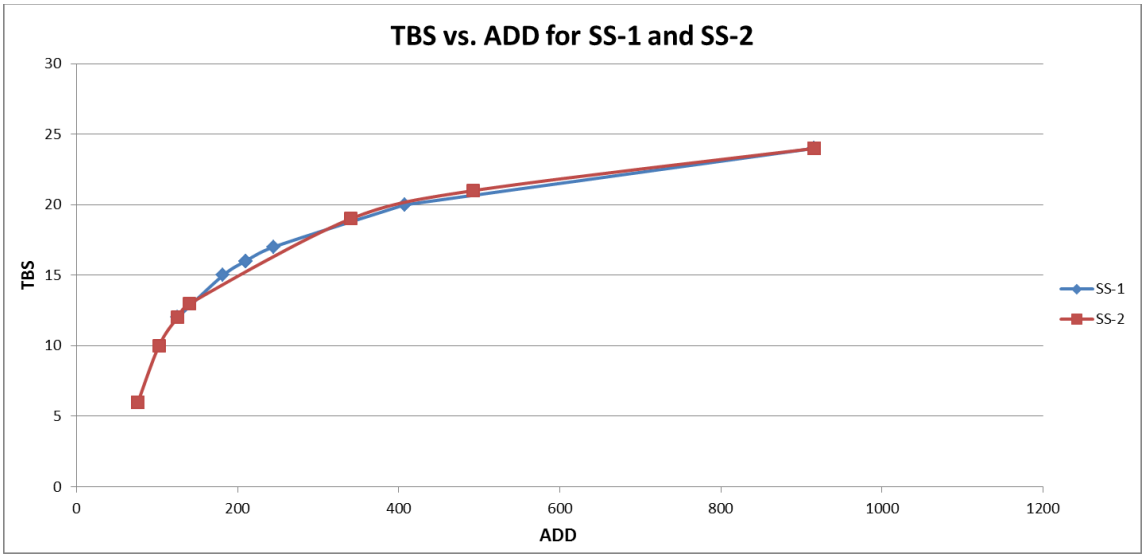

Figure 32: The relationship of TBS and ADD for SS-1 compared to the relationship of TBS and ADD for SS-2

Arthropod Observations

Insects were observed throughout the study on both SS-1 and SS-2. Most insects were seen on both carcasses; however the amount of each species varied between both specimens. In addition, as a result of the different weather affecting each specimen, the time when the insects were present and in what stage they were observed also varied (Table 59). SS-1 had flies present throughout every decompositional stage, even later into the advanced stage of decomposition (Richardson, 2012). A few beetles like Red-Legged Ham beetles, Giant Hairy Rove beetles, and Burying beetles (only seen on SS-1) were present in the advanced stage before and after stasis. The rest of the beetles were observed in the advanced stage after stasis and the Ichneumon Wasp was only seen on SS-1. SS-2 differed greatly in the beginning stages of decomposition as a result of the cold weather. No insects were seen in the fresh stage that lasted a week, or in the early

stage before stasis that lasted 20 days. The rest of the insects were observed during the early stage after stasis and into the advanced stage.

Table 59: Species of insects present in the different stages of decomposition for SS-1 and SS-2 (Richardson, 2012)

Insects observed	**SS-1: Decomposition stages insects were present**	**SS-2: Decomposition stages insects were present**
Blue Bottle Fly (*Calliphora vomitoria*)	Fresh, Early, Advanced before and after stasis	Early after stasis, Advanced
Black Blow Fly *(Phormia regina)*	Fresh, Early, Advanced before and after stasis	Early after stasis, Advanced
Common Toad Fly (*Lucilia silvarum*)	Fresh, Early, Advanced before and after stasis	Early after stasis, Advanced
Flesh Fly (*Sarcophagidae*)	Fresh, Early, Advanced before and after stasis	Early after stasis, Advanced
Dung Fly *(Scathophagidae)*	Advanced after stasis	Early after stasis, Advanced
Cheese Fly *(Piophila casei)*	Advanced after stasis	Advanced
Ichneumon Wasp (*Ichneumonoidea sp.)*	Advanced after stasis	Not seen
Dung Beetle (*Aphodius distinctus*)	Advanced after stasis	Early after stasis, Advanced
Burying beetle *(Nicrophorus)*	Advanced before stasis	Not seen
Northern Carrion Beetle (*Thanatophilus lapponicus)*	Early, Advanced before and after stasis	Early after stasis, Advanced
Black Larder Beetle (*Dermestes ater)*	Advanced after stasis	Early after stasis, Advanced
Sap Beetle *(Nitidulidae)*	Advanced after stasis	Early after stasis, Advanced
Giant Hairy Rove Beetle *(Creophilus maxillosus)*	Advanced before and after stasis	Early after stasis, Advanced
Hide Beetles *(Dermestes maculatus)*	Advanced after stasis	Early after stasis, Advanced
Dermestidae sp	Advanced after stasis	Early after stasis, Advanced
Red-legged Ham Beetle *(Necrobia rufipes)*	Early, Advanced before and after stasis	Early after stasis, Advanced
Hister (Clown) Beetles *(Histeridae)*	Advanced after stasis	Early after stasis, Advanced

CHAPTER 5: DISCUSSION

SS-1 and SS-2 followed the overall expected pattern of decomposition for western Montana; however, the final stage of skeletonization was never reached. The end results for both SS-1 and SS-2 was complete mummification of external soft tissue, never reaching skeletonization in the 365 days of the study. The rate of decomposition was at a much slower speed than expected compared to other geographic locations. Montana's cold weather was likely responsible for the remains decomposing at a slower rate and stasis in the decay process affected the timing of decompositional events. The Megyesi et al. (2005) method of calculating ADD resulted in the underestimation of the estimated ADD compared to the actual ADD, consequently underestimating the estimated PMI.

Rates and Patterns of Decomposition

The process of decomposition is expected to follow a predictable rate and pattern (Clark et al., 1997). However, when different variables are added it can become more complex. By understanding the way those variables affect decay in Montana and why it deviates from the expected rate and pattern can help investigators interpret taphonomic events to a body after death. The rate and pattern of decay that both SS-1 and SS-2 went through was compared to the "normal" process of decomposition and to one another to better understand how western Montana's environment specifically affects decomposition.

Overall for both specimens the rate of decay was slower than expected. Rigor mortis usually occurs within 2 to 3 hours after death and lasts for around 48 hours (Clark et al., 1997). SS-1 was in rigor by the time of deposition at the site, yet rigor lasted for 4 days instead of the expected 48 hours. SS-2 was also in rigor by the time of deposition, but promptly froze making the estimation

of length of time spent in rigor impossible. Algor mortis occurred as expected for both SS-1 and SS-2. By the time of arrival at the research site lividity had set in as expected for SS-1. SS-2 also showed the beginning of lividity and the impressions of the ropes that held the body in place during transport could be seen. Wardak and Cina (2011) discussed the idea that as a result of cold temperatures deoxyhemoglobin cannot occur which can leave the skin a pink color instead of the purple colored lividity. This was observed with SS-2, in which the remains stayed pink for many months during the cold winter.

SS-1 and SS-2 both went through the processes of autolysis and putrefaction, although neither of them followed the expected rate of each. Autolysis causes the breakdown of cells in the dermis and epidermis and is expressed externally by the presences of fluid filled pockets of skin called bullae and also by skin slippage (Clark et al., 1997; Pinheiro, 2006). Bullae started to form on SS-1 on the ventral surface along the nipples, between the back legs, and along the leg creases by day 3, 10/3/11 (Figure 4). The epidermis was also starting to slough off on the lower abdomen on day 8, 10/8/11 (Figure 6). Visual signs of autolysis occurring externally also were observed on SS-2, although it differed drastically. Skin slippage was seen on the inside of the front legs and also between the back legs on day 141, 4/20/12.

Internally autolysis of the red blood cells is expressed by a purple colored marbling on the surface of the remains. Marbling was observed on the ventral surface, between the front legs, and back legs of SS-1 on day 2, 10/2/12 and lasted until day 3. For SS-2 the cold weather induced stasis was responsible for the retardation of autolysis externally. Autolysis of the red blood cells did occur earlier in the decay process and marbling was observed by day 9, 12/10/11. Light purple marbling was visible on the posterior end of the remains and on the ventral surface. By

day 28, 12/29/11 stasis started in the decomposition process halting the marbling in place until the middle of March when signs of putrefaction took its place (Figure 15).

Putrefaction is the buildup of gasses produced from the bacteria that are released inside the body after death that causes remains to bloat (Clark et al, 1997; Pinheiro, 2006). The process of putrefaction followed the expected pattern and again the rate was a little slower than expected for SS-1. The remains began to bloat after death and by day 2, 10/2/11, the right legs came off the ground. The maximum abdominal measurement was reached on day 4, 10/4/11, at 132.5cm (Figure 4) and the bloat lasted for 27 days ending with the legs coming back together on day 28, 10/28/11. The process of putrefaction was different for SS-2 as well. Bloating was abnormal and for one day only on day 9, 12/10/11, the back right leg came off the bottom left leg 1cm even though the abdominal measurement was still 107.4cm. This again occurred on day 22, 12/23/11, and last for 6 days with the back leg touching down on 12/29/11. On day 99, 3/9/12, the remains begin to swell as if filling with fluid. By 4/3/12 the bloat was 121.1cm and the pig still looked swollen and wide but the feet were still touching. Finally on day 141, 4/20/12, the bloat was 121.5cm and the feet finally came off the ground but never exceeded being parallel to the ground and stayed that way until 5/13/12. The maximum abdominal measurement of 123.2 was reached on day146, 4/25/12, with a total difference of 13.7 cm through the whole bloating process (Figure 19). For SS-1the difference was 13.5cm, however the carcass looked more bloated with the legs spread wider. SS-2 just looked swollen and like the cadaver was retaining fluid instead of ballooning out.

Another byproduct of putrefaction is blood and tracheobronchial foam being pushed out of the nose and mouth from the pressure of bloating (Pinheiro, 2006). On day 2, 10/2/11, blood began to bubble out the nose onto the ground below the snout lasting for 4 days, until the

maximum bloat was reached. On day 90, 2/29/12, bright red blood starts foaming out of SS-2's nose onto the ground. Blood continued to leak out of the nose for 25 days finally ceasing on 3/25/12. Color change to the remains is associated with putrefaction, as the gases produced from the bacteria interact with the hemoglobin a greenish blue color is produced called sulfohemoglobin (Clark et al, 1997; Pinheiro, 2006). On day 3, 10/3/11, SS-1's ventral surface was a dark purple greenish blue color. The tongue turned a teal color on day 5, 10/5/11, and the chest and upper abdomen turned grayish green/blue (Figure 4). This phenomenon usually lasts for a short period of time; however SS-1 stayed a greenish color until day 197, 4/15/12, well into the advanced stage of decomposition which is abnormal. SS-2 was never as greenish blue as SS-1 was. On day 103, 3/13/13, the ventral surface started turning darker purple, yellow, green, and blue (Figure 18).

There are two processes that can alter how remains decompose by slowing or preventing the remains from reaching skeletonization 1) saponification which is the formation of adipocere and 2) mummification (Pinheiro, 2006). This study found that for both SS-1 and SS-2 adipocere and mummification were a part of the decomposition process. For SS-1 thick white adipocere was first observed on the right side of the neck on day 153, 3/1/12. A few days later a stalactite like formation of waxy yellowish white adipocere was observed in the tear on the posterior end of the remains. However, most of the adipocere was found along the dorsal side of the remains with the most concentrated areas being in the lumbar region. Adipocere was last observed on the remains on day 253, 6/9/12, lasting for 100 days. Adipocere was also observed on SS-2 although not as much was produced and did not last for as long of a period of time. A few drops were observed dripping out of the mouth on day 145, 4/24/12, but were no longer seen the next day. The other

area adipocere was located was on the dorsal side of the remains in the lumbar region. It was first observed on day 233, 7/12/12 and lasted for 66 days ending on 9/25/12.

Mummification, or the drying of soft tissue, occurs in warm or cold arid environments (Clark et al., 1997; Pinheiro, 2006). Desiccation of soft tissue has been seen in other areas that conduct decomposition research. Bass (1997) noted that it occurs in Tennessee in cases where the remains are in the direct sunlight, causing photosensitive maggots to leave a protective covering of skin over them while they eat. Arizona's arid climate often results in rapid mummification of soft tissue; however most often the remains still ultimately skeletonize (Galloway et al., 1989; Galloway, 1997). Rhine and Dawson (1998) claimed that mummification in New Mexico was complicated and that conditions needed to be just right, preferably slightly damp and slightly cooler temperatures often found in the areas of higher elevation. Previous studies conducted in Montana in the Lubrecht Experimental Forest showed that the pigs deposited in August, October, and November 2008 all mummified, never reaching skeletonization (Dudzik, 2009; Parson, 2009). McKeown et al. (2011) concluded that unless remains were scavenged by animals, remains deposited in western Montana will stay mummified for a long period of time, possibly years. Mummification was also the end result for both SS-1 and SS-2 (Figures 13 and 24). For both sets of remains, after the advanced stage of decomposition began the soft tissue began to dry out ultimately leading to complete desiccation of the soft tissue.

SS-1 and SS-2 moved through the stages of decomposition differently than remains studied in other geographic locations. SS-1 was deposited on October 1, 2011, and stayed in the fresh stage of decomposition of only the first day (Table 5). By day 2, 10/2/11, the remains moved into the early stage of decomposition with the manifestation of autolysis and putrefaction; however the ambient temperature began to decrease causing the early stage to last longer than expected,

26 days, and ending on 10/28/1. On day 28, 10/28/11 the advanced stage of decomposition began with the ceasing of bloat. The remains stayed in the advanced stage for 17 days until on 11/14/11 the remains entered a cold weather induced stasis in the decomposition process halted all changes to the remains for 116 days. Day 161, 3/9/12, the remains began to slowly change again entering back into advanced decomposition in which it stayed for the next 125 days until full mummification was reached on day 286, 7/12/12 lasting until the end of the study on 10/1/12. Skeletonization was never reached.

SS-2 followed the same pattern as SS-1, however the rate in which it moved through the stages was significantly different. SS-2 was deposited on December 2, 2011, and stayed in the fresh stage of decomposition for 7 days due to the below freezing ambient temperatures for that week (Table 6). On day 9, 12/10/11, the remains slowly moved into early decomposition for 19 days with the beginning of faint marbling on the ventral side and posterior end. The remains entered a stasis decomposition process on day 28, 12/29/11, with no decay changes to the remains for 61 days. The ambient temperature began to increase causing the remains to enter back into the early stage of decomposition with the beginning of bloat on 2/28/12 lasting for 75 days. SS-2's abdomen began to deflate on day 164, 5/13/12, marking the beginning of the advanced stage of decomposition in which the remains stayed for 69 days until full mummification occurred which lasted 134 days until the conclusion of the study on 12/2/12. Skeletonization was not reached after 365 days.

The weather was warmer for SS-1 allowing the remains to move all the way through to the advanced stage of decomposition before going into stasis. As a result of the remains being introduced to below freezing temperatures before SS-2 was even deposited, SS-1 was in stasis for 55 days longer than SS-2. The cold weather induced stasis caused SS-1 to remain in the

advanced stage for 338 days, however even if the stasis did not occur the time spent in the advanced stage most likely would have been the same. The remains may have moved more quickly to the later descriptions of the advanced stage, but it is very unlikely that skeletonization could have been reached. Due to the stasis, SS-2 stayed in the early stage of decomposition for an abnormal length of 158 days. SS-2's unique environment during the time of decomposition directly led to the slowing of the rate in which the remains went through the stages of decay.

Decomposition in Montana

Terneny (1997) was the first person to conduct research on decomposition using pigs in western Montana and also happens to be the first study to be conducted in the Missoula Valley. The surface specimen was deposited in April, 1998 and was not protected from scavenging and as a result is not comparable to the rate and sequence of decomposition for SS-1 and SS-2. However, the results from this study are still beneficial to understanding decomposition in western Montana and help to understand how those different variables affected the rate and pattern of decomposition (Table 60).

Wagster (2007) was the first researcher to try and understand Montana's unique and rapidly fluctuating weather. Her findings were similar to how SS-1 and SS-2 experienced postmortem changes. She found that cold weather did slow down and stasis occurred with the remains never reaching skeletonization. This idea was reinforced by both SS-1 and SS-2, they moved through the stages of decomposition at a slower rate while ending in complete mummification. She was the first to observe maggots over wintering in the remains, a phenomenon seen with this research especially with SS-1. She also observed the wolves that were deposited during the winter had a pink coloring to their teeth, supporting the findings that

pink teeth can be a sign of the remains freezing. Both SS-1 and SS-2 exhibited pink coloring to the anterior teeth throughout the study.

Gonder (2008) focused on looking at decomposition during different seasons. She too found that cold weather slowed down decomposition. She made an important observation relevant to the results of this study, the remains that had been frozen did not fully bloat as much as the remains deposited in warmer months. This lessening of bloat was observed with SS-2 in this study.

Table 60: The results of Montana studies investigating the rate of decomposition using pigs as proxies

Studies	Fresh Stage of Decomposition	Early Stage of Decomposition	Advanced Stage of Decomposition	Skeletonization	Extreme Decomposition
Terneny April, 1998	3 days	7 days	27 days	105 days	157 days
Parsons August, 2008	1 day	5 days	244 days*	0 days	0 days
Parsons and Dudzik October, 2008	180 days	54 days	40 days*	0 days	0 days
Dudzik November, 2008	146 days	53 days	42 days*	0 days	0 days
Spencer October, 2011	1 day	26 days	338 days*	0 days	0 days
Spencer December, 2011	7 days	156 days	203 days*	0 days	0 days

*Using the Galloway et al. (1989) method of classifying decomposition, mummification is included in the advanced stage of decomposition.

Parsons (2009) found that decomposition in Lubrecht followed the same patterns as studies conducted in other geographic locations, although the rate was slower in western Montana. The remains deposited in August, 2008, LSS-1, decomposed a lot faster than LSS-2 and exponentially faster than SS-1 and SS-2 (Table 60). The difference between the remains deposited in Lubrecht on October, LSS-2, and SS-1 is that it was colder at the time of deposition of LSS-2 resulting in the pig freezing right away staying in the fresh stage for 180 days. SS-1 slowly reached the advanced stage of decomposition before stasis making how the remains changed after stasis drastically different from one another. Parsons also confirmed that LSS-1 had more insect activity than LSS-2.

Dudzik placed the third pig at Lubrecht on November 20, 2008, LSS-3, and it too froze upon deposition. She did not find many differences between the rate of decomposition between LSS-2 and LSS-3 (Table 60). This was not the case for SS-1 and SS-2; they differed greatly from one another. SS-1 slowly reached the advanced stage of decomposition before stasis while SS-2 froze just after early decomposition began. This resulted in drastically different changes between the remains after stasis concluded.

Variables affecting decomposition in western Montana

Climate

Ambient temperature is argued to be the most important variable affecting decomposition and second to that is relative humidity, and from previous decomposition studies done in western Montana researchers agree that Montana's unique weather affects the rate and pattern of decay differently. Tennessee has higher humidity along with high ambient temperatures during the summer, which can lead to rapid skeletonization of remains (Bass, 1997). Montana is more arid

than Tennessee and this study supports the idea that in arid and hot environments mummification is often seen. Bass also suggests that direct sunlight causes maggots to leave a protective skin covering while feeding. SS-1 and SS-2 were in direct sunlight throughout the study and ultimately mummified possibly agreeing with Bass's statement. However, the pigs deposited in the Lubrecht Experimental Forest were partially protected from direct sunlight by the pine tree canopy above them and mummification still occurred with all three pigs placed in August, October, and late November (Dudzik, 2009; Parsons, 2009).

Arizona is more similar to Montana than Tennessee. The summers are arid and hot with cooler winters, although Montana winters are drastically colder (Galloway, 1997). Galloway states that remains mummify in the warmer months and decay slower in the winter, similar to western Montana. She also notes that remains ultimately skeletonize in Arizona; however most of the cases used in her study have evidence of animal scavenging. New Mexico has a wide variety of microenvironments like Montana (Rhine and Dawson, 1998). A difference between remains found in New Mexico and remains found in Montana is that the remains from New Mexico that are not scavenged can still reach skeletonization in 2 months, whereas non-scavenged remains in Montana often stay mummified. Mummification does occur in New Mexico and Rhine and Dawson note that it occurs in the areas with higher elevations similar to Montana.

Ambient temperature and humidity found at Lubrecht is fairly similar to the Missoula Valley with a few differences that did make a difference between the two studies. October 2008 was a colder month than October 2011 in the Missoula Valley. The colder weather caused LSS-2 to freeze upon deposition. SS-1's rate of decomposition was slower due to the colder weather; however it was not cold enough to freeze the remains until the middle of November 2011. Also it

snowed earlier in Lubrecht in 2008 than in the Missoula Valley in 2011. During the spring the weather in Lubrecht was similar to the Missoula Valley, enough so that the decomposition was similar between LSS-2, LSS-3, SS-1, and SS-2.

Cold Climate Decomposition

Cold and freezing ambient temperature is a very interesting, complex, and poorly understood variable in decomposition. It has been known for a while that cold weather slows down or halts decomposition, the main question is how do you tell if and how long remains have been frozen or in stasis for? Mann et al, (1990) notes that sometimes remains that have been frozen turn an orange or black color and grow mold. SS-2 froze right after deposition and by day 3, 12/4/11, the internal temperature reached 29°F (-1.67°C) and stayed within 1° for 87 days when on 2/29/12 the internal temperature started to increase. The remains stayed a pinkish red color until day 47, 1/17/12 when they turned orange along the right side of the abdomen and posterior half of the pig. On day 149 4/28/12 the orange color increased in intensity also adding red to the ventral side of pig along the sternal rib ends and also on the posterior end (Figure 20). The ventral surface at midline also turned black. Orange coloring was never seen with SS-2. Mold however was observed on both sets of remains. Small round patches of white, brown, and orange mold were first seen on SS-1 on day 125, 2/2/12, along the right side of the neck and along the outside of the right front arm. SS-2 had more mold than SS-1 with small patches of white, orange, and black mold covering the right side of the remains beginning on day 103, 3/13/12 (Figure 18).

Cold climate decomposition has been studied in Edmonton Canada, again showing that decomposition is slower in colder climates (Komar, 1998). However, Komar concluded that full skeletonization can be reached in 4 months compared to the 6 weeks in warmer weather. It was

noted that 16 of the 20 cases had scavenging. Again, it is known that in western Montana remains likely only skeletonize if they are scavenged (Mckeown et al., 2011). This information makes it hard to compare decomposition rates to Komar's study because of the scavenging. It would be of great interest to know how fast remains decompose in Canada without scavenging.

Micozzi (1986, 1997) found that temperatures below 39.2°F (4°C) halted decomposition and bacterial growth while preserving the soft tissue, which was observed in this study especially with SS-2. As a result of stopping the bacterial growth when the remains thaw the putrefaction is not as intense, this can be expressed by the lack of colors to the skin and less bloat. Majority of SS-1's chest and abdomen turned a bright teal color while SS-2 only had a small patch of a greenish tint at midline on the ventral surface and between the back legs. Bloating was different for each pig. SS-1 began to bloat right after death and reached full bloat on day 4, 10/4/12 with the legs spread wide apart (Figure 4). SS-2's bloat stayed within one cm of 107.0cm for 96 days from 12/5/11 to 3/9/12. When the remains began to bloat reaching the maximum measurement on day146, 4/25/12,they became wider and looked like it was filling with fluid instead of bloating with the top legs only becoming parallel with the ground (Figure 19).

Micozzi (1986, 1997) also supports the idea that freezing causes the epidermis to break down which ultimately leads to remains decompose from the outside to the inside, as compared to remains that have not been frozen decomposing from the inside out. The results of this study do not support that idea. Both SS-1 and SS-2 decomposed from the inside, and not even outwards as majority of the soft tissue stayed intact throughout the whole study. Micozzi also noted that remains that have been frozen have a more rapid hair loss. SS-2 did not lose anymore hair than SS1; however that may be different with humans. Another result he found was that previously frozen remains tend to have more mummified tissue. Both SS-1 and SS-2 mummified, although

SS-1 did stay moist longer with the skin staying soft longer. SS-2's skin did dry and become harder quicker than SS-1. The last observation that Micozzi made about remains that have been previously frozen is that they have more insect active. This was not supported by this study. SS-1 had more insects overall than SS-2, including larger maggot masses.

The presence of pink colored teeth can be an indication of freezing. Kirkman et al. (1977) conducted a study to try and better understand this phenomenon. They found that tissue located in the pulp chamber of a tooth can undergo autolysis which produces a red color staining inside the tooth. This can most often been seen in incisors, canines, and premolars. They concluded that pink teeth are observed in more moist environments and can be caused by freezing, heating, submersion in water, and toxins. Both SS-1 and SS-2 had pink teeth during the study. A pink coloring to the incisors was observed on day 23, 10/23/11, gradually becoming a darker pink and spreading to the canines and premolars (Figure 10). The pink lasted until day 122, 1/30/12. SS-2's teeth were unobservable until day 99, 3/9/12, however when they could be seen the incisors and canines were pink. The color stayed until day 202, 6/20/12.

Arthropods

Insects are an extremely important aspect of decomposition. Insects control the rate of removal of soft tissue, which in turn affects the rate of decomposition (Haskell et al., 1997). Parsons (2009) and Dudzik (2009) recorded the forensically important insects during their study of decomposition in Lubrecht Experimental Forest and found that the actual amount of insects present on the remains was different than other geographic locations. An entomological study conducted in Edmonton Canada investigated the difference between pig carcasses decomposing outdoors compared to carcasses decomposing inside a house (Anderson, 2011). She found that if

fewer insects are present on remains the rate of decomposition noticeably slows. If Parsons (2009) and Dudzik's (2009) hypothesis stating that there are less insects in Montana is true, then decomposition may always be a little slower than other geographic location no matter how the weather is affecting decomposition. A goal of this study is to document the forensically important insects found in the Missoula Valley to see if Parson's and Dudzik's conclusions hold true for this specific area.

As a result of the slow decomposition and how long SS-1 stayed moist, flies were present throughout every stage of decomposition, even later into the advanced stage (Table 58). Fly eggs were first observed on day 2, 10/2/12, however many rounds of oviposition occurred producing maggots of differing instars and sizes located all over the remains and it also resulted in maggots being present on the remains from day 5, 10/5/12 to day 276, 7/21/12. Two species of insects were observed on SS-1 only, burying beetles, seen in the advanced stage of decomposition before the stasis occurred, and Ichneumon Wasps, seen in the advanced stage of decomposition after the stasis occurred. Only two species of beetles were observed during the early stage of decomposition, the Northern Carrion beetle and the Red-Legged Ham beetle. Those two species along with the Giant Hairy Rove beetle were the only other beetles seen in the advanced stage before stasis occurred, most likely feeding on the smaller maggots and no other beetles were witnessed during the fresh or early stages of decomposition. The rest of the beetles present throughout decay were observed in the advanced stage of decomposition after stasis occurred and most were present until the end of the study. The maggots migrated off to pupate differently than expected; they trickled off in small groups through most of the advanced stage of decomposition after the stasis. SS-1 overall had more insects present throughout decomposition

than SS-2 did. SS-1 also had larger maggot masses that extended farther away from the body than SS-2.

Due to the cold climate at the time of deposition of SS-2 none of the first responding insects were seen until the early stage of decomposition after stasis occurred on day 99, 3/9/12. Like SS-1, SS-2 had flies throughout the early stage after stasis and also all throughout the advanced stage again as a result of the remains staying so moist (Table). The first fly eggs were observed on day 136, 4/15/12 and flies oviposited many different times producing many different instars and sizes of maggots. Maggots were observed on the remains first on day 141, 4/20/12 and were last seen on day 224, 7/12/12. Also differing from SS-1 were the beetles that were present during the advanced stage of decomposition for SS-1 were all observed on SS-2 in the early stage of decomposition after stasis which continued until the last day of the study. The maggot masses were smaller than SS-1 and stayed inside the remains the whole time. The only beetles that did not follow the expected succession were the Red-Legged Ham beetles. According to Haskell et al. (1997) Red-Legged Hams are supposed to arrive to the remains about the time skeletonization begins. For both SS-1 and SS-2 they were seen during the early stages of decomposition and were actually the beetles that were present most often in the highest amounts.

The entomological results of this study support the hypothesis introduced by Parsons (2009) and Dudzik (2009), that western Montana has fewer forensically important insects than other geographic locations. Insects are also greatly affected by Montana's unique weather, especially during the fall and winter seasons, an example being the first fly eggs were not oviposited on SS-2 until day136, 4/15/12, when usually flies arrive to the scene within minutes (Haskell et al., 1997). Fly eggs normally hatch within a few hours of oviposition and it is believed that temperatures below freezing (0°C) can kill un-hatched eggs (Mann et al., 1990).

That was not found to be accurate for this study and an example being that on day 8, 10/8/11, fly eggs were oviposited along the dorsal side of the carcass and the ground, they stayed in stasis for 13 days with ambient temperatures reaching 26°F (-3.33°), they finally hatched on day 21, 10/21/11when the temperature reached 60°F (15.56°C).

Haskell et al. (1997) discussed the ideas that different stages of insects or maggots all present on the remains at the same time or if they are not following the expected patterns means an outside force has affected the remains, possibly that the body has been moved. These phenomena are observed with both SS-1 and SS-2, but are due to the fluctuating weather and the many different waves of eggs that were oviposited. Maggots also stayed in stasis when the ambient temperatures dropped below freezing. There was evidence of maggots surviving the entire winter and stasis period, an example of this occurred on day 182, 3/20/12, when a large cream colored maggot was observed on the ground under the posterior end of SS-1, at that time the ambient temperature had not been warm enough for a maggot to reach the third instar and could only have wintered over in the remains.

The fall and winter seasons, and most likely the stasis, affected the sizes of the maggot masses for SS-1 and SS-2. Although the maggot masses were a little larger for SS-1 than SS-2, they were not as large as the masses that were on the pig deposited in August, 2008 in the Lubrecht Experimental Forest (Parson, 2009). Alongside this study a fellow graduate student from the University of Montana deposited one pig on the ground and one in a burial on a private ranch in the Bitterroot Valley south of Stevensville, MT on May 26, 2012 (Huey, 2013). The surface pig had more insect activity than SS-1 and SS-2. The maggot masses were large and extended out from the ventral surface almost 61.0cm. This difference in maggot mass size may be a result of the differing ambient temperatures. Maggots that are feeding during colder months

may stay closer to the body and within the body for protection. Also this study found that remains that decompose during the colder months have less seepage of fluids which may also dissuade the maggot masses from extending away from the body.

Investigating the Method of Accumulated Degree Days

For calculating the estimated postmortem interval, the method of ADD only takes temperature into consideration and while it is one of the most important variables affecting decomposition, there are other variables that are also important to how a body decays (Megyesi et al., 2005). ADD may be useful for translating qualitative data into quantitative data, however it may not tell the whole taphonomic story and as a result it may give inaccurate postmortem interval estimations.

The sequential order of the descriptions of decomposition created by Megyesi et al. (2005) to categorize observations may not work for decomposition in other specific geographic locations. The descriptions failed to accurately describe how SS-1 and SS-2 went through the stages of decomposition making it difficult to fit the actual observation into the categories. An example for SS-1 of this issue was that the descriptions that matched the observation made on SS-1 had a tendency to place the remains in the wrong stage of decomposition. On day 46, 11/15/11, (actual PMI of 46 days) SS-1's remains were abnormally discolored best matching the description of the trunk as "discoloration changing from green to black" and given a score of 5 points, which is considered part of early decomposition. The remains stayed "changing from green to black" receiving 5 points until day 167, 3/15/12 (actual PMI of 167 days) even though the remains had been in the advanced stage of decomposition for a while (Tables 11-20). Finally

by 7/15/12 (actual PMI of 289 days) all three body areas of scoring were classified as in the advanced stage, though remains have been considered in the advanced stage since 10/28/11.

Montana's cold winter weather created a problem for the method of ADD. The frequent amount of 0°C days receiving a 0 as the average temperatures were added together to find the estimated ADD made PMI estimation imprecise. Also for some months the TBS did not change due to the remains being in stasis, this was an issue because the TBS stayed small with a resulting low ADD while the actual ADD kept increasing with time. For SS-1the TBS was scored as 16 on day 76, 12/15/11, giving the estimated ADD of 209.89 degree days (actual PMI of 65 days). The actual ADD at this time was 1864 degree days. The remains were in stasis causing no observational changes to occur resulting in the same TBS of 16 for a total of 4 months. On day 167, 3/15/12, the estimated ADD was still 209.89 degree days while the actual ADD had increased to 3113 degree days (actual PMI of 167 days). When the remains came out of stasis the changes did not occur fast enough for the TBS to ever get large enough to come close to an accurate estimated ADD. The relationship between the TBS and ADD was compared for each specimen individually and then the two specimens were compared to one another (Figure 32). SS-1 decomposed at a little faster rate in the beginning of the study with a resulting higher TBS. However, SS-2 froze right after deposition scoring a lower TBS for a longer period of time. Eventually after the ambient temperatures increased in the spring, decomposition continued slowly resulting in a gradual increase in TBS and consequently gradually increased the ADD. Both pigs gradually reached full mummification in a similar way, plateauing with a final TBS of 24 and ADD of 916.22.

By day 289, 7/15/12, (actual PMI of 289 days) SS-1's TBS reached the maximum score for this study with mummification in all three body zones (Tables 27 and 28). With a TBS of 24

the resulting estimated ADD was 916.22 degree days (estimated PMI of 13 days) when the actual ADD was 9587 degree days (actual PMI of 289 days). The end result for this study was mummification so the TBS stayed 24 until the very last calculation on day 351, 9/15/12, again with a resulting ADD of 916.22 degree days (estimated PMI of 16 days) compared to the actual ADD of 13785 degree days (actual PMI of 351 days) (Tables 26-32). With having the highest scored description being dry bone there was never a chance for SS-1 to receive a high enough score to give an accurate estimation of ADD.

ADD never correctly estimated the actual day of death for SS-1. SS-2 was different in that for the first month the calculation overestimated the day of death by 5 days, the second month underestimated the actual day of death by 34 days, and the third month underestimated the day of death by 69 days; however the 80% confidence interval did capture the actual day of death for all three months (Tables 34-39). After that though, the ADD no longer correctly predicted the actual day of death. The TBS slowly increased for SS-2, but it was not fast enough to keep up with the increasing actual ADD, even though the actual ADD did not increase as fast due to the high number of days below freezing. The TBS of 24 was reached on day 258, 8/15/12, (actual PMI of 258 days) with all three body zones reaching mummification. Again the estimated ADD was 916.22 degree days (estimated PMI of 13 days) and the actual ADD for the day was 9972 degree days (actual PMI of 258 days) (Tables 50 and 51). The ADD stayed the same until the last calculation for SS-2 on day 350, 11/15/12, with an estimated ADD of 916.22 degree days (estimated PMI of 28-29 days) and an actual ADD of 14598 degree days (actual PMI of 350 days).

The method of ADD was first investigated for western Montana in the Lubrecht Experimental Forest by Parsons (2009) and continued with Dudzik (2009). Dudzik found the

same issues with ADD that was found with SS-1 and SS-2, winter and stasis caused the TBS to be too low and when decomposition began again after the thaw it was too slow to catch up to the actual ADD making the distance between the estimated ADD and the actual ADD too large and also consequently making the distance between estimated PMI and actual PMI too large. This study found that the results of SS-1 and SS-2 being in the advanced stage of decomposition at the end of the study and never reaching skeletonization was a problem, never allowing for the TBS to get high enough to get close to the actual ADD, an issue that Dudzik also discussed. Her ultimate finding was the method of ADD produced an underestimation of the estimated postmortem interval in western Montana, which the findings of this current research fully supports. The results of this study also supports Dudzik's recommendation that the scoring system needs to be altered for better use in environments that are arid and mummification is the end result. The outcome of this current research gives more evidence that the method of ADD needs to be a better fit for the unique decomposition in western Montana to achieve more accurate estimations of the postmortem interval.

Obstacles with cold climate decomposition

Conducting research in below freezing conditions poses some unforeseen difficulties. Most of the problems that occurred during the study were directly related to the intense and unpredictable weather. The freezing ambient temperatures present for the three months straight had some negative effects on some of the equipment. Not only were ThermoWorks's waterproof Thermadata Series II Temperature Loggers difficult use and at times did not work properly, they faltered a couple as a result of the below freezing temperature. Batteries did not hold a charge long in the freezing temperatures and on days where the temp was 25°F (-3.89°C) and below the time-lapse cameras would not function. The freezing temperature during one site visit even cause

the probe to snap off the handheld digital thermometer, requiring a new one of the same brand to be purchased. Over time the cloth tape measures would crack and started to break and were reinforced by duct tape.

Scavenging is always an issue with decomposition studies. In the Missoula Valley one of the most prevalent scavengers is the Black-Billed Magpie (*Pica hudsonia*), their persistence and uncanny way to squeeze through tight places made it challenging to prevent entry into the cages. One inch chicken wire was place over every surface of the enclosures to keep them out. Although precautions were taken to prevent rodent scavenging, it occurred anyway due to the nature of rodents. Rodent activity was the highest when the weather was bad, so when snow covered the ground food most likely would have been scarce. Also towards the end of the study when the remains were mummified rodent activity increased. It became a variable that was ultimately unable to be controlled for, an example being that rodents tunneled under SS-2's enclosure and came up through a hole in the middle of the cage. Rodent scavenging was very well document throughout the study. On the SS-2 it introduced two entryways into the body and most likely sped up decomposition a little, however it is hard to predict how big of an affect it actually had on the remains. The end result would have been the same, it mummified.

Areas of further research

There are many areas of future research that need to be explored to better understand decomposition in western Montana. As mentioned earlier, mummification of soft tissue should be looked at more closely. Understanding the factors and rate and pattern of desiccation can give a better PMI estimation in western Montana. Also it would be interesting to deposit a pig in the Missoula valley in April to see how the rate and patterns compare to SS-1 and SS-2 having gone

through cold weather induced stasis and freeze-thaw. It would help to better specify the variables that affect cold weather decomposition and give better ways to tell if remains have frozen and for how long. Even in the warmer weather, remains deposited in April should still decompose slower than if placed in the warmer months, but bloat should occur more normally, have more normal colors, and insects would most likely be different, more, and maggot masses larger. More studies also need to be conducted in the Missoula valley in the warmer months. It would be interesting to see how fast the remains move through the stages of decomposition in the hot months of July and August. Huey (2013), started research in the Bitterroot valley south of Missoula. Further research should be conducted to not only compare to Missoula and Lubrecht, but to create a baseline dataset for that specific area. The Bitterroot Mountains are frequented by hikers and hunters and understanding decomposition could help solve cases that occur in the Bitterroot.

CHAPTER 6: CONCLUSION

It is important to have an understanding of decomposition in specific geographic locations. By having a baseline dataset for decomposition with known and expected rates and patterns, investigators will be able to compare unknown cases to the dataset to better understand how different variables are affecting decomposition. For this study one pig was deposited on the ground in a protective enclosure on October 1, 2011(SS-1) and one pig was deposited in a separate enclosure on December 2, 2011(SS-2). The first hypothesis investigated by this study was that remains deposited in western Montana during winter months decompose at a different rate and sequence than remains deposited in other geographic locations. Both SS-1 and SS-2 were affected by western Montana's cold winter climate which did alter the expected pattern of decomposition by resulting in mummification and never reaching the skeletonization stage of decomposition. The rate in which the remains moved through the decay process was significantly different for each set of remains. SS- 1 stayed in the fresh stage of decomposition for 1 day before moving into the early stage of decomposition which lasted for 26 days. The remains then slowly entered into the advanced stage of decomposition where they stayed for 17 days before the cold weather induced stasis started. SS-1stayed in stasis without any changes to the remains for 116 days until the ambient temperature warmed up enough for decay to resume. The advanced stage lasted for 125 days until mummification was reached lasting for 80 days until the conclusion of the study. Skeletonization was never reached. SS-2 stayed in the fresh stage of decomposition of 7 days before slowly entering the beginning of the early stage of decomposition. The remains stayed in the early stage for 19 days before stasis started, which lasted for 61 days. After stasis concluded the remains moved back into the early stage of

decomposition, where it stayed for another 75 days. SS-2 stayed in the advanced stage of decomposition for 69 days before mummifying which lasted for 135 days until the conclusion of the study. Skeletonization was not reached for these remains either.

Cold and freezing ambient temperatures have a huge impact on the rate of decomposition; however, it is complex variable that needs to be better understood so more accurate postmortem interval estimations can be made. Many researchers agree that the cold weather drastically slows down decomposition and also that remains decompose differently after they have been frozen. What needs to be better documented are the visual signs that the remains having been frozen and for how long. It needs to be emphasized that decomposition occurring in cold weather, especially in western Montana, may result in PMI underestimation, though some observations were made as a result of this study than may be able to more accurately estimate PMI.

The second hypothesis tested, if remains are frozen and stasis occurs in the decay process the remains exhibit visual evidence that both events occurred, was accepted. Insects were found to be a good indication of cold weather decomposition. Remains found in the late fall, winter, or spring that have fewer bugs than expected most likely started decomposing after the cold weather started around October. If the remains are found in the cold winter months and are in the fresh or early decomposition stage with no signs of insect activity, it is highly probable that the remains were deposited after the temperature dropped below 40°F (4.44°C). The past ambient temperatures at the recovery site would need to be collected, and when the date the temperature decreased below 40°F and stayed low may be close to the day of death. If remains are found in the late fall and have different instars and sizes of maggots all present on the remains it may indicate that the remains were deposited after October. The same can be said if

remains are found in the early spring. If large maggots are found and the weather has not yet been warm enough for the maggots to reach that size, they may have over wintered indicating that the remains were deposited sometime in the fall. Maggot mass size may also be an indicator that remains had been frozen at one time. If remains are found in the spring and the maggot mass is smaller than expected or located within the remains without extending away from the body, it may be a sign that the remains were there long enough to freeze and were not just deposited.

Other visual signs of cold weather decomposition are a result of the bacteria freezing inside the remains which decreases the intensity of putrefaction. Remains that are found in the spring that were deposited in the winter should have less of the putrefactive coloring of the greens and blues. Also bloating may differ with the limbs never fully spreading to their full width. The remains may look more swollen, like they are retaining fluid rather than bloating. Also the skin may appear be orange, an indication that the remains were at one time frozen and not freshly deposited. If the incisors, canines, and premolars are tinted pink it may also mean that the remains have been frozen.

Another way to better estimate the postmortem interval if the remains are found in the winter still in the fresh or the beginning of the early stage of decomposition and are frozen is to take an internal temperature. If the internal temperature of the remains is below freezing, in this case with the pigs within a few degrees of 29°F, then the day of death may be able to be estimated. The ambient weather for the recovery site needs to be collected and the day found when the temperature dropped below 40°F and stayed around freezing. That day may be the day of death.

The method of using ADD to better estimate PMI by transforming qualitative data to quantitative data is becoming more popular and a favored method to use. Initial testing of the ADD method in western Montana indicated that it created inaccurate results and underestimated the actual length of decomposition (Parsons, 2009; Dudzik, 2009). This study found that the unique Montana weather affected decomposition differently than other geographic locations making the current system of ADD inaccurate for this specific climate. Ambient temperatures below 0°C and stasis in the decomposition process created problems when trying to use the scoring system, ultimately producing a TBS that was too small to be able to reach the actual ADD. When the ambient temperatures finally begin to increase the remains start to decompose again, but too slowly for the estimated ADD to catch up with the actual ADD and consequently never allowing for the estimated PMI to catch up with the actual PMI. The points allotted for mummification is an issue in an environment that has the end result of mummification. The TBS for mummification is not high enough to get a large enough estimated ADD resulting in largely underestimated estimated PMI compared to actual PMI.

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