Environmental Effects on Human Decomposition in the Palouse Region

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by

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Authorization to Submit Thesis

This thesis of Xiu Hui Carlson, submitted for the degree of Master of Arts with a major in Anthropology and titled "Environmental Effects on Human Decomposition in the Palouse Region," has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Understanding how environment affects the decomposition process of a corpse is crucial in assisting forensic investigations. In winter, decomposition, insect activity and animal scavenging decrease due to low temperatures which cause preservation. Decomposition, insect activity and animal scavenging increase in the summer. During spring and fall, decomposition can occur in addition to adipocere formation and preservation depending on the ambient temperature as temperatures during daytime and evening can be vastly different. Further studies are needed to develop a more specific timeline for decomposition in the Palouse region.

Acknowledgements

It is a pleasure for me to thank those people who have contributed for this and made it possible. First of all, I would like to express my sincere gratitude to my thesis advisor Dr. Donald Tyler for providing me the necessary direction from the start of the research to the final phase. He carefully listened to all my queries and would calmly solve it. Not to mention, he has been extremely patient with my slow progress in finishing my thesis.

My gratitude also extends to my committee members Dr. Robert Lee Sappington and Dr. Kenneth Locke. Their mentoring and encouragement have been especially valuable. Dr. Sappington's insights on the burial conditions especially the burial depth was enlightening. Dr. Locke's suggestion to compile the environmental effects into graphs for easier understanding was really appreciated.

Dedication

I would like to dedicate this thesis to my supportive husband Alan, who kept me going through this long three years and always being there for me. I am truly thankful for having you in my life. To my two little ones, Michael and Victoria who gave me the chance to be a mother, life has never been the same. I love you both to the moon and back.

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CHAPTER 1

Introduction

The death of an organism is always followed by the breakdown of its body and cellular structure. Interestingly, some cadavers undergo decomposition while others undergo preservation. The reason for the different fates of cadavers is the conditions in which they exist. For example, a hot and humid environment usually accelerates the process of decomposition, while in cold and dry conditions the process is slowed. The understanding of how the environment can affect the decomposition of cadavers is vital in the reconstruction of the context of death and the estimation of postmortem interval (PMI or time since death) in forensic cases. Investigation is aided by providing information such as who the victim is; the cause of death; and where, when, and how the victim died. However, estimating the postmortem interval can be difficult.

The purpose of this study is to investigate and compare previous studies on how cadavers decompose in different environments biologically and naturally which can then be applied to how the conditions in the Palouse region (a region that comprises parts of southeastern Washington, north central Idaho, and parts of northeast Oregon) might affect decomposition. Similar studies have been performed in different locations but none of them include all of the environmental factors mentioned and none address the Palouse region. Existing data from studies performed on human decomposition (Forbes et al. (2005), Forbes et al. (2005a), Forbes et al. (2005b), Vass (2001), Haglund et al. (1989), Kjorlien et al. (2009), Joseph et al. (2011), and Carlo et al. (2001)) are used to generate an approximate timeline that could be useful in predicting the PMI or to dissect the process of decomposition for corpses in various environments. Obtaining the average seasonal temperature and humidity for an area will help to shrink the range of the PMI. The summer months (June - August) show an acceleration in the decomposition process because humidity and warm temperature favor insect activity and animal scavenging. Therefore, late spring (March - May) going into summer and early fall (September - November) should be the most favorable period of time for active decomposition to take place. Decomposition should be greatly decelerated when the winter season (December - February) begins. Due to the cold and occasional freezing temperatures, it is difficult for insects and animals to be active. Bacterial decomposition within the body would also decrease. As a result, a victim who died during the winter season would be expected to have a larger PMI range as the decomposition process is much slower. Insect activity and animal scavenging would increase when the weather warms back up, which can make it difficult for the forensic investigators to estimate the PMI for the cadaver.

Taphonomy is the study of decaying organisms over time and how they may become fossilized. Forensic taphonomy is the study of human decomposition especially in burial sites. The human body is composed of cells which are the basic, structural, functional and biological unit of all living organisms. When death occurs, the body stops regulating its internal processes which leads to autolysis. Autolysis is a process where the body starts decomposing itself internally as oxygen levels decrease, causing the decrease of pH (numeric scale that measures of acidity or basicity of an aqueous solution) in the cells. In the external environment, the body will also undergo decomposition via insect activity and animal scavenging. The rate of decomposition is affected both internally and externally by the environment the body is in. Overall, colder climates tend to retard decomposition, animal scavenging, and insect activity on a corpse while warmer climates tend to accelerate the rate of decomposition, animal scavenging, and insect activity.

A body left at a burial site can experience either preservation or decomposition depending on the environment with which it comes into contact. If preservation takes place, a cadaver created even decades ago can be preserved so well that someone without enough experience might misinterpret the time of death. When a body starts to decompose, the rate of decomposition is affected by the environment. The same goes for the preservation of the body. According to a study done by Joseph et al. (2011) in a tropical rainforest environment, it was found that the decomposition process was best categorized into five stages: the fresh stage (days 1-2), bloated stage (days 2-7), decay stage (days 5-13), post-decay stage (days 10-23), and remains stage (days 18-90+).

Autolysis generally begins approximately four minutes after death has occurred (Vass (2001)). While the body experiences autolysis internally, signs of decomposition can be noticed externally: algor mortis, livor mortis, and rigor mortis. Algor mortis is the reduction of body temperature after death. Livor mortis is the blood pooling into areas of the body which leads to skin discoloration. Rigor mortis is the hardening of the muscle. Putrefaction follows autolysis where soft tissues of the body are destroyed by micro-organisms, resulting in bloating. Further putrefaction and scavenger activity leads to decay of the body, revealing the bones. The last stage of decomposition is diagenesis, where the body and bones begin to dry up, which is part of skeletonization.

The rate of decomposition of a cadaver is greatly influenced by its surroundings. Factors such as temperature, soil pH, the presence of moisture, oxygen levels, the usage of coffins and even clothing types within the burial site can alter the rate of decomposition. These environmental factors can create a favorable environment for bacteria growth, which inevitably leads to decomposition, or create unfavorable conditions for bacterial survival that initiates the preservation of a cadaver. The preservation of the cadaveric material then begins, which can be seen by the formation of adipocere.

Adipocere, often called "grave wax," is a grayish-white or tan (depending on whether it was formed from white or brown body fat), soap-like substance that is produced when a body experiences postmortem changes. The firm cast of adipocere of corpses allows for the estimation of body shape, facial features, and injuries in the well-preserved corpses. Corpses of women, infants, and overweight persons are particularly more favorable to adipocere formation because they contain a higher fat to body ratio (Gill−king (1997)).

Saponification, the chemical process of adipocere formation, came to be understood in the 17th century when microscopes became widely available. The formation of adipocere takes place when the neutral fats of decomposing bodies undergo hydrolysis and hydrogenation, which produces a mixture of predominantly saturated fatty acids such as myristic, palmitic and stearic acids (Forbes et al. (2005)). However, their individual presences are dependent on the decomposition environment. The optimum condition for adipocere formation is a damp, warm, and anaerobic environment (Forbes et al. (2005)).

Besides biological breakdown, nature also participates in the decomposition of a cadaver via insects and animals scavenging. At death, the cells in the body start dying and the enzymes begin to digest the cells. Bacteria present in the gastrointestinal tract start destroying soft tissues, and producing liquids and gases. The volatile gases, called apeneumones escaping from the decomposing body, attract necrophagous insects that feed on decaying tissues (Joseph et al. (2011)). The study of insect activity in the process of cadaver decomposition and its application in criminal investigation is called Forensic Entomology. Insects involved are mostly true flies or Diptera; they usually lay their eggs on the natural body openings and wounds. The eggs hatch into larvae known as maggots which feed on the moist flesh. Once they have grown to their full size, they stop feeding and move to drier areas to form pupae. These insects can be useful in the estimation of PMI, movement of the corpse, manner and cause of death, and association of suspects at the death scene. The rate of larvae development depends on the surrounding ambient temperatures. By mapping out the number of life cycle(s) of a species, a forensic entomologist can use the information to determine the PMI of a cadaver. The same environmental factors that affect the decomposition of a cadaver can also affect insect activity on a cadaver. Cold temperatures slow down the decaying of organic matter while warm temperatures increase the number and type of insect infesting the corpse (Carlo et al. (2001)). Cadaver buried deeper than one foot saw no sign of insect colonization (Carlo et al. (2001)). Animal scavenging, like insect activity, is not uncommon for a cadaver. Cadavers that are left in areas accessible to animals will usually attract scavengers. A fresh wound on a cadaver attracts and encourages animal scavenging. The skin and flesh portion of the face and neck are usually the first choice for scavenger removal (Haglund et al. (1989)). Scavengers then begin to disarticulate the bones and carry them off.

The degree of disarticulation of bones done by animals during scavenging depends on the degree of decomposition; in a less decomposed state, the joints are still connected with each other, hence scavengers wander off with the whole arm rather than just the humerus, radius, or the ulna, which happens more commonly if the cadaver is in a later state of decomposition (Kjorlien et al. (2009)). Animal scavenging can leave tooth marks on the cadaver which can be mistaken for mutilation of the body. Therefore, the understanding of animal scavenging and animals' teeth mark patterns will help forensic investigators avoid inaccuracies. Buried cadavers, depending on the depth of burial or properly wrapped cadavers, can avoid being disturbed by animals or delay scavenging activity (Kjorlien et al. (2009)).

CHAPTER 2

Literature Review

The purpose of this chapter is to provide a summary of the studies used in this thesis. For decomposition and adipocere formation, Forbes et al. conducted three studies on the effect of burial environment on adipocere formation by alternating soil pH, temperature, moisture, and oxygen content, effect of soil type, and effect of method of burial on adipocere formation. Vass (2001) wrote an article to describe the process of decomposition of cadaver. As for insect activity, Joseph et al. (2011) examine the role of forensic entomologist in assisting with criminal investigation where insects and other arthropods are involved. Carlo et al. (2001) explain the factors affecting the development of Diptera which is crucial in estimating PMI. Haglund et al. (1989) and Kjorlien et al. (2009) explore the scattering patterns of skeletal remains by scavengers.

Decomposition/adipocere formation

1. The effect of soil type on adipocere formation (Forbes et al. (2005))

This study was done using different types of grave soil in which the burial had taken place to test their effects on the formation of adipocere. X-ray diffraction and particle size analysis were used to characterize the soils based on their grain size. The results did not differentiate one type of soil from the other in adipocere formation.

2. The effect of the burial environment on adipocere formation (Forbes et al. (2005a))

This study was conducted to test how and if the conditions of a soil burial environment affect the preservation of decomposing tissue via adipocere formation. The factors include soil pH, temperature, moisture and the oxygen content within the grave site. Infrared spectroscopy, inductively coupled plasma-mass spectrometry, and gas chromatography-mass spectrometry was used to determine the lipid profile and fatty acid composition of the adipocere formed. In conclusion, a burial environment with cold temperature, lime, and aerobic conditions indicated a reduced or inhibited rate of adipocere formation while a mildly alkaline pH, warm temperature, and anaerobic conditions encouraged the formation of adipocere. However, the results are useful for demonstrating the effect of an individual burial factor on adipocere formation and cannot be generalized for all burial environments.

3. The effect of the method of burial on adipocere formation (Forbes et al. (2005b))

This study tested the effect of burial method such as the presence of coffin and clothing types on the formation of adipocere. The results confirmed that adipocere formed more readily on a body buried directly in the soil as compared to a body buried in a coffin. Tissue wrapped in clothing, plastic, or polyester clothing was favorable to adipocere formation.

4. Beyond the grave-understanding human decomposition (Vass (2001))

This article explains the process of human decomposition. A cadaver begins to decompose at the moment when death occurs. Human decomposition has been described as taking place in four stages: fresh (autolysis), bloat (putrefaction), decay (putrefaction and carnivores), and dry (diagenesis). Studies on human decomposition help answer four questions: who is the victim, how did the victim die, where did the victim die, and when did the victim die? Additionally, the study of the products of decomposition can be useful in locating human remains or clandestine grave sites by cadaver recovery dogs.

Insect activity

1. The Use of Insects in Forensic Investigations: An Overview on the Scope of Forensic Entomology (Joseph et al. (2011))

This paper examines the role of forensic entomology which is the study of the application of insects and other arthropods in criminal investigation to estimate the time of death or PMI, movement of corpse, manner and cause of death and association of suspects at the death scene.

2. Factors Affecting Decomposition and Diptera Colonization (Carlo et al. (2001))

This study explores the factors that inhibit or favor the colonization and development of Diptera (true flies). Such knowledge would be crucial for estimating the PMI when true flies are found among other insects on a cadaver. Only certain species are attracted to the cadaver when it is in certain stage of decomposition. With that, a forensic entomologist would be able to estimate the time since death by analyzing the species found on a cadaver. Temperature, access to the cadaver, and burial depth are the factors reviewed in the study.

Animal scavenging

1. Canid Scavenging/Disarticulation Sequence of Human Remains in the Pacific Northwest (Haglund et al. (1989))

This study was conducted to determine if there was a pattern in the consumption of human remains by canid scavengers. Variables affecting scavenging and disarticulation by animals are human population density of the area in which the remains are discovered, circumstances which protect the remains from scavengers, position of the remains, the cause of death, behaviors of the scavenging species, season of year, amount of food available, number of individuals feeding, and size relationship of scavenger to carcass. Results demonstrated that there was a pattern and could be categorized into sequential stages: Stage 0 - no bony involvement; Stage 1 - ventral thorax damaged and one of both upper extremities removed; Stage 2 - lower extremity involvement; Stage 3 - only vertebral segments remain articulated; and Stage 4 - total disarticulation.

2. Scavenging Activity Can Produce Predictable Patterns in Surface Skeletal Remains Scattering: Observations and Comments from Two Experiments (Kjorlien et al. (2009))

This study explains that the scattering patterns of skeletal remains by scavengers and the effect of the presence of clothing on scavenging. A carcass in a later stage of decomposition will have more bone elements found close to the original placement point. If the carcass is in an earlier stage of decomposition, there will be fewer bone elements found close to the original placement point. Also, scavengers preferred unclothed carcasses in open environmental contexts compared to clothed carcasses and in wooded situations.

The information above can be summarized to show that the optimum conditions that favor adipocere formation are mildly alkaline pH, warm temperature, anaerobic condition, and wrapped in clothing, plastic, or polyester. By examining the species of insect found on the cadaver, forensic entomologist would be able to assist in estimating the time since death as certain species are attracted to the cadaver at a certain stage of decomposition. Animal scavenging activity depending on the degree of decomposition of the cadaver could be categorized into stages from no bony involvement to total disarticulation.

CHAPTER 3

Decomposition/Adipose Formation

This chapter focuses on how different environments such as soil pH, temperature, moisture, soil type, and clothing type affect the process of decomposition and adipose formation. The analysis is applied to the environment in the Palouse during the spring, summer, fall, and winter season where general timelines are generated.

Internal decomposition begins in organs that contain enzymes that break things down into simpler forms. Digestive organs such as the stomach, liver, pancreas, duodenum, and the intestines, are among the first organs that start decomposing. The circulatory organs such as the heart, blood, and heart muscle experience a similar decomposition time frame as the digestive organs. Connective tissues and integument (skin) are the last part of the body to decompose because they do not have a high concentration of enzymes. The skin acts as a barrier to provide the internal organs' protection from external influences.

Tissue decomposition begins in cells with the highest rates of ATP (Adenosine triphosphate) synthesis, biosynthesis, and membrane transport. Figure 3.1 shows the usual order of tissue decomposition which begins in the internal organs making its way to the external organ (Gill−king (1997)). Physical changes in the appearance of the corpse would be noticeable.

Table 3.1 explains the five major categories of decomposition using the Arizona-Sonoran Desert as an example. These physical appearances can be compared roughly with a corpse in an unknown stage of decomposition. However, the difference in the environments, the desert and the place where the corpse is found, should be kept in mind when making comparisons. According to Galloway (Galloway (1997)), the remains of a corpse can be classified into five major categories: 1) fresh, 2) early decomposition, 3) advanced decomposition, 4) skeletonization, and 5) decomposition of skeletal material; and it can be categorized as below:

The presence and concentration of oxygen in the burial environment affect the rate of

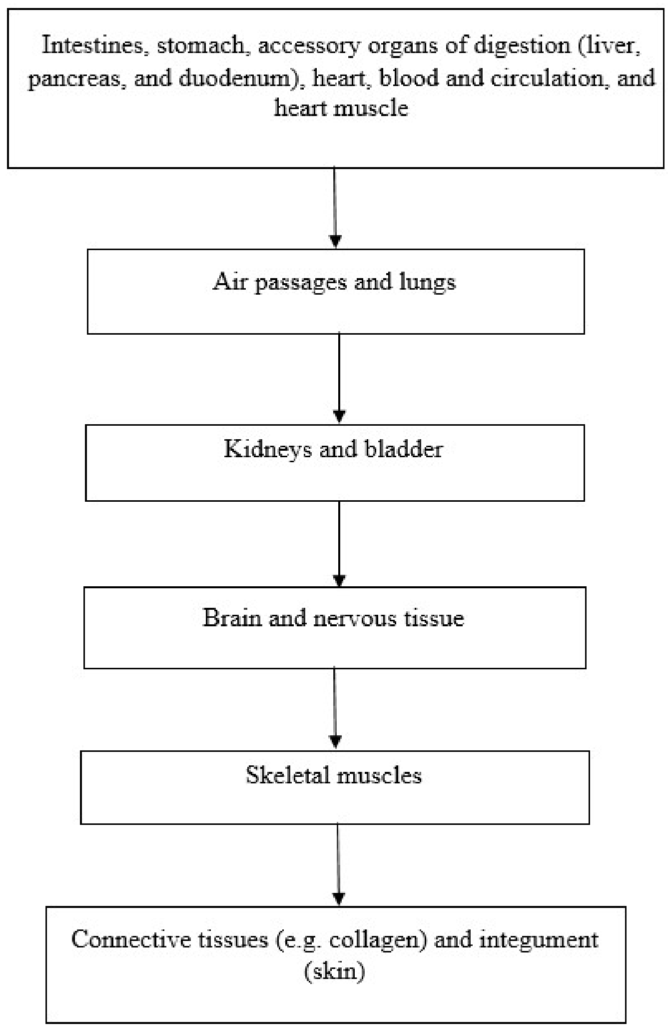

Figure 3.1: The Order of Tissue Decomposition

A. Fresh	1) Fresh, no discoloration or insect activity 2) Fresh burned
B. Early decomposition	1) Pink-white appearance with skin slippage and some hair loss 2) Gray to green discoloration, some flesh relatively fresh 3) Discoloration to brownish shades particularly at fingers, nose, and ears; some flesh still relatively fresh 4) Bloating with green discoloration 5) Post bloating following rupture of the abdominal gases with discoloration going from green to dark 6) Brown to black discoloration of arms and legs, skin having leathery appearance
C. Advanced decomposition	1) Decomposition of tissues producing sagging of flesh, caving in of the abdominal cavity, often accompanied by extensive maggot activity 2) Moist decomposition in which there is bone exposure 3) Mummification with some retention of internal structures 4) Mummification of outer tissues only with internal organs lost through autolysis or insect activity 5) Mummification with bone exposure of less than one half the skeleton 6) Adipocere development
D. Skeletonization	1) Bones with greasy substances and decomposed tissue, sometimes with body fluids still present 2) Bones with desiccated tissue or mummified tissue covering less than one half the skeleton 3) Bones largely dry but still retaining some grease 4) Dry bone
E. Extreme decomposition	1) Skeletonization with bleaching 2) Skeletonization with exfoliation 3) Skeletonization with metaphyseal loss with long bones and cancellous exposure of the vertebrae

Table 3.1: Categories and Stages of Decomposition (Galloway (1997))

decomposition as aerobic bacteria and fungi often found on decomposing remains require sufficient oxygen to survive and multiply. Delay in decomposition is seen in an environment where air circulation is at minimal, encouraging preservation.

The pH of the soil with which the body is in contact is crucial as a highly acidic or highly alkaline environment will inhibit bacterial growth and thus inhibits decomposition. The degree of inhibition depends on how far on the end of the pH spectrum of the soil is. The study (Forbes et al. (2005a)) done using a mildly alkaline environment demonstrated that adipocere forms within a pH range of approximately 5-9 where the presence of an extreme acidity (pH 5) environment appeared to retard the decomposition process and yield adipocere. The retardation was likely due to the inability of many bacteria to survive in a highly acidic environment. With a lower abundance of bacteria in the environment, the rate of decomposition and/or conversion to adipocere would have to be lower. The highly acidic environment was not entirely inhospitable to bacteria and the resultant product formed was considered to have the fatty acid composition characteristic of adipocere. In the burial environment using lime, it was noted that decomposition and the formation of adipocere were considerably inhibited with the most likely reason that lime inhibits survival and proliferation of bacteria caused by its extremely alkaline nature (Forbes et al. (2005a)).

The temperature of the burial environment can have a significant effect on decomposition. "Most bacteria thrive at an optimal temperature of approximately 98.6 °F" (Forbes et al. (2005a)). Since the soil temperatures are usually much lower than 98.6 °F, bacterial growth may be inhibited. "Putrefactive activity is greatly inhibited at temperatures below 50 °F or above 104 °F" (Forbes et al. (2005a)). In a study (Forbes et al. (2005a)) done using different temperatures between 71.6 °F and 104 °F there was no notable impact on the formation of adipocere because bacteria in this range of temperatures would survive and thrive in the tissue and surrounding soil. In extremely hot conditions (e.g. greater than 104 °F), bacteria lost the ability to survive in addition to the rapid desiccation of the tissue which prevented the formation of adipocere. The cold burial environment used in the study was not favorable to adipocere formation and partly inhibited decomposition. It must be noted, however, that the cold soil environment used cannot be compared to cold icy environments such as glaciers. The case of the Iceman who was discovered in the Tyrolean Alps in 1991 has demonstrated that adipocere can form in cold, glacial environments (Forbes et al. (2005a)).

An extreme cold temperature has shown to lead to the preservation of a cadaver. Such cases can be seen from the discovery of a frozen, mummified body, complete with tattoos dating from 400 B.C. found on St. Lawrence Island, Alaska and the body of a Neolithic voyager dating from approximately 4000 to 6000 B.C. found frozen in a glacier on the border between Austria and Italy with remarkable preservation of soft tissue, skin, and tattoos (Micozzi, 1997). Temperature has a direct effect on bacteria growth. “Freezing stops bacterial growth and preserves tissue by influencing cell division time ... At temperatures below 55 °F (12 °C) bacterial reproduction is greatly retarded Micozzi (1997). At temperature between 32 to 41 °F (0 to 5 °C), bacterial multiplication stops entirely ... Thus, 4 °C provides an effective low temperature threshold below which bacterial growth is severely retarded” (Micozzi, 1997). Therefore, variance in surrounding temperature will affect the breakdown of cellular material by bacteria in a cadaver.

In a study done by Forbes, excess water showed an increase in the formation of adipocere, whereas the lack of moisture in a dry soil environment can also divert decomposition to preservation due to the moisture in the body itself (Forbes et al. (2005)).

The type of grave soil in which the cadaver is buried can also affect the rate of decomposition. The composition of soil is different from sand as the conditions of their particles are different. According to Forbes, the soil and sand environments were both successful in adipocere formation but the adipocere formed in sand was more stable which may be caused by the effective draining properties of sand which accelerates the formation of adipocere (Forbes et al. (2005)).

In a study done to determine whether the clothing types used during the burial had any effect on adipocere formation, it was shown that the plastic bag and cotton clothing burial environment did not induce adipocere formation. On the other hand, polyester clothing has the ability to retain moisture which may have aided the formation of adipocere (Forbes et al. (2005b)).

According to Table 3.1 in chapter three of this thesis, Galloway created the categories and stages of decomposition based on a place that has a very different climate compared to Palouse region, the Arizona-Sonoran Desert. Table 3.2 shows the average precipitation in inches calculated for the Palouse region and Arizona Sonoran Desert to provide a comparison of total precipitation in both areas which is used to determine if the decomposition process would be affected similarly. The temperature in the Arizona-Sonoran Desert is approximately 20-30 °F higher than Palouse and the average total precipitation for the desert is about three times less than Palouse [see Table 3.2]. However, the table can still be used as a guideline in categorizing decomposition since bodies generally break down in a similar fashion. What changes, however, is the time scale. There may not be much mummification for bodies located in Palouse due to higher precipitation compared to the desert.

Good air circulation is crucial for decomposition to occur. Bacteria found on decomposing remains is aerobic, hence it requires sufficient oxygen to survive and multiply. Besides aerobic bacteria, fungi are also found in decomposing remains. Therefore, an environment such as an airtight container with no air circulation would encourage preservation. However, there are other factors that should be considered as well that can push for decomposition instead of preservation in an airtight container.

Being too far at either end of the pH spectrum would lead to preservation, as most bacteria cannot survive high acidity or alkalinity. Decomposition would then most likely lean toward slight adipocere formation or total preservation. At pH 5, which is considered an extreme acidic environment, the decomposition process is retarded and instead adipocere is formed. According to Oregon State University, the majority of soils in the Palouse area in 1980 had pH less than 6.0. Due to the long-term use of high rates of ammonium-based nitrogen fertilizers, it can be assumed that the soil pH will become more acidic as time passes unless a different fertilizer has been used in the last decade (Mahler, 2002). Therefore, a body found in the Palouse area would undergo adipocere formation or preservation if there were no other environmental factors to be accounted for.

Most bacteria in the Palouse does not have the capability to survive extreme temperatures. Bacteria responsible for decomposition are no different. Therefore, ambient temperature plays an important role in decomposition. The optimal temperature for bacteria to thrive is approximately 98.6 °F. Soil holds heat in the daytime and releases it during the night. During the daytime, even with the sun shining on the soil, the temperature of the soil will not reach the ambient air temperature. Soil in the shade will have a much lower average temperature than the soil constantly in the sun. During the night, soil releases the heat it absorbed during the day, since the soil is warmer than the ambient air temperature at night. The average temperature in the Palouse area during the years 1893-2005 did not reach 98.6 °F. It could be logically assumed that the average soil temperature rarely, if ever reached 98.6 °F either. Therefore, bacterial growth in the soil would be inhibited and adipocere would form or formation would be encouraged.

Table 3.3 shows the average maximum and minimum temperature for each season in the Palouse region which are used in calculation to predict the summary of the decomposition process [Figures 3.2 - 3.4] for each season in the area. Figure 3.2 demonstrates a prediction pattern of the decomposition process that would take place in the Palouse region in the summer months. In the daytime, the temperature is ideal for decomposition to happen. However, the temperature during the nighttime in the summer months could drop below the optimal temperature which could interrupt the decomposition process that was taking place during the day. The acidic soil in the Palouse region could cause some adipocere formation even when decomposition is happening. The presence of oxygen would encourage decomposition depending on its content while a non-oxygenated environment would lead to preservation. Figure 3.3 is a chart showing the predicted decomposition process that would take place in the Palouse region during the spring and fall. Based on the average maximum and minimum temperature for both seasons, only slight decomposition or some preservation would occur. Having moisture in the soil as well as being acidic in the Palouse region would cause for adipocere formation. Presence of oxygen would determine whether the corpse would undergo decomposition or preservation. Figure 3.4 shows the predicted pattern of how a corpse would decompose in the winter months in the Palouse region. It is predicted that decomposition would most probably not happen due to the low average temperature. Since the temperature of the soil would regulate to the surrounding temperature, the soil temperature would be lower than the optimum temperature for any decomposition to happen and preservation would instead. The presence of moisture and oxygen would lead to preservation or adipocere formation. The presence of oxygen should not have any effect on decomposition as the temperature is low enough for corpse to be preserved.

	Figure 6.1 (Palouse)	Figure 6.2 (Arizona)
January	0.10	0
February	0.08	0
March	0.09	0.05
April	0.07	0.02
May	0.07	0
June	0.08	0.03
July	0.05	0.02
August	0.02	0.14
September	0.05	0.07
October	0.05	0.05
November	0.10	0.05
December	0.13	0.05
Average precipitation (inches)	0.074	0.028

Table 3.2: Calculated average precipitation in inches for the Palouse region (based on University of Idaho data) and Arizona Sonora M Desert, Arizona based on Figures 6.1 - 6.2

Season/Months	Average max in °F	Average min in °F
Winter (December-February)	37.1	24.5
Spring (March-May)	56.7	35.8
Summer (June-August)	79.3	48.8
Fall (September-November)	59.1	37.4

Table 3.3: Average maximum and minimum temperature for each season in the Palouse region from 1893-2005

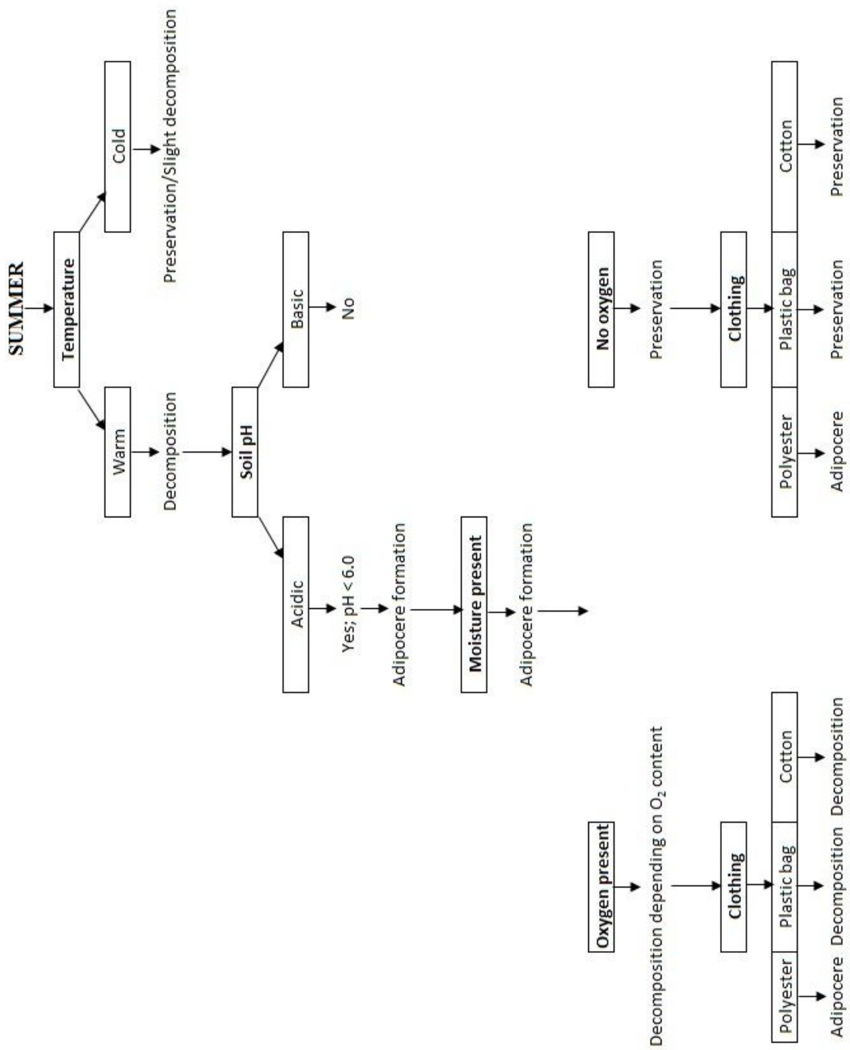

Figure 3.2: Decomposition process prediction in the summer in the Palouse region

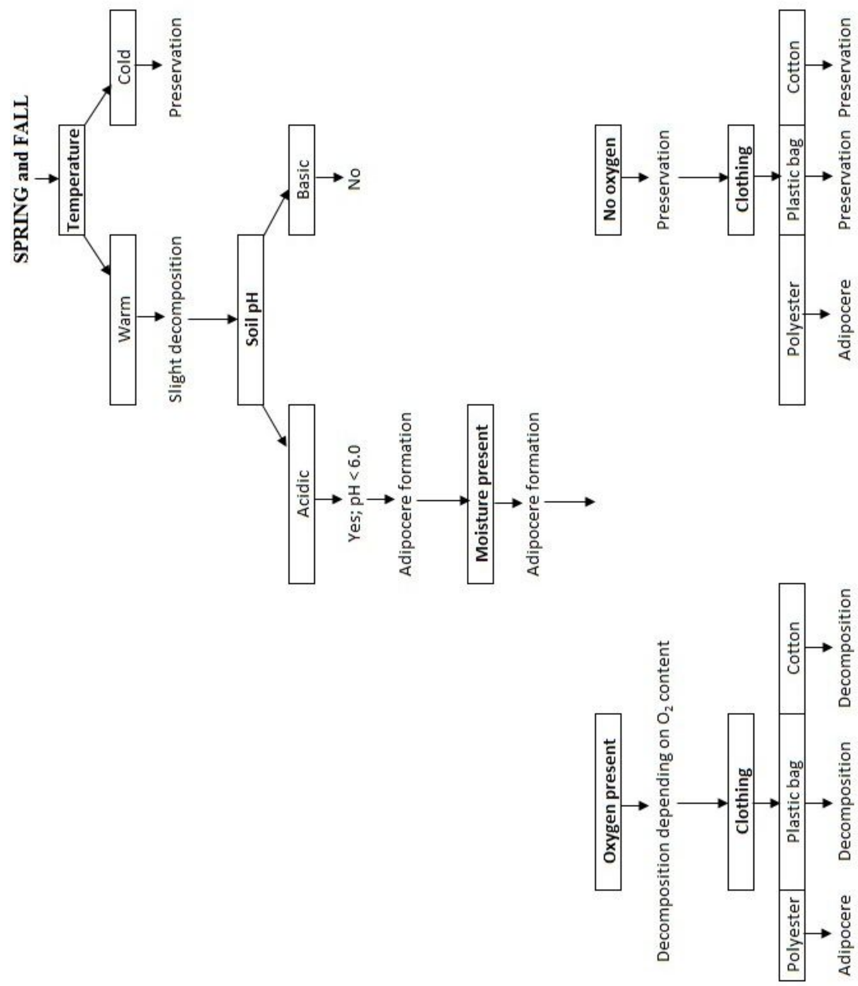

Figure 3.3: Decomposition process prediction in the spring and fall in the Palouse region

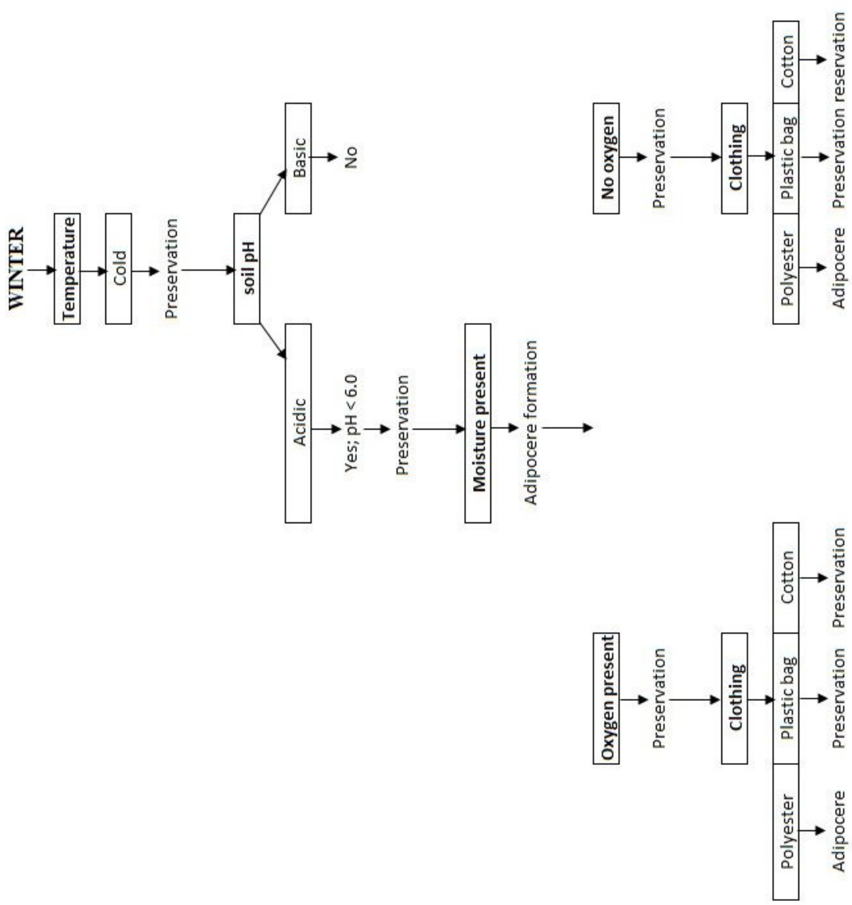

Figure 3.4: Decomposition process prediction in the winter in the Palouse region

CHAPTER 4

Insect Activity and Animal Scavenging

This chapter concentrates on how insect activity and animal scavenging take part in the decomposition process. Insects are attracted to the corpse as it begins to decompose. They are usually the first to arrive at the decomposing body if accessible. By studying the types of insect found on the corpse, investigators will be able to predict the PMI. Animal scavengers are attracted to the corpse as a source of food. Parts of the corpse would be torn off and carried away by scavengers. It is important to investigators to not mistake animal scavenging activity with dismemberment.

As the body begins to decompose internally, insects are attracted by the stench released from decomposition. "Insects are major players in nature's recycling effort, and in nature a corpse is simply organic matter to be recycled" (Goff (2001), p. 9). There are four main categories of carrion species: necrophagous species (those that feed directly on the corpse), predators and parasites of necrophagous species (those that are attracted to the necrophagous feeding on the dead body), species that feed on both body and arthropods, and species that use the body as an extension of normal habitat, such as spiders (Goff (2001), p. 22). The invasion of a dead body by insects follows a definite pattern if the body is intact, without open wounds or external bleedings. Figure 4.1 shows the general pattern of the insects' invasion, unless there is any open wound, on a corpse beginning from the eyes, nose, mouth, ears, to the anus and genitals if those parts are exposed.

Blood or wounds provide additional points of entry and attract insect activity. Wounds inflicted before death (antemortem injuries) or at the time of death (perimortem injuries) are more attractive to insects than those inflicted after death (postmortem injuries) because they often bleed profusely. Wounds inflicted after death when the heart is no longer pumping produce little if any blood and are not as attractive to insects. Insect activity may alter the characteristics of any kind of wound, but insect activity during the early stages of decomposition associated with areas other than natural body openings should alert investigators to

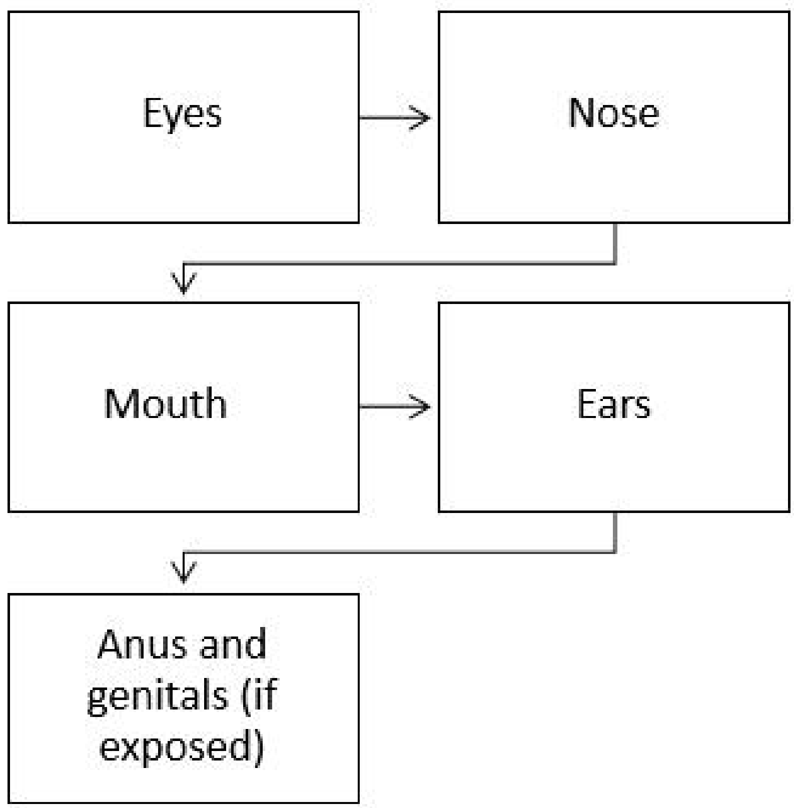

Figure 4.1: Pattern of insects' invasion on corpse

the possibility of antemortem or perimortem wounds (Goff (2001), pp. 26-27).

According to the studies done by K. Tullies and M. L Goff on exposed carrion in a tropical rainforest, it was found that the decomposition process was best divided into five stages on the basis of physical appearance of carcasses, internal temperatures and characteristic insect populations (Joseph et al. (2011)):

1) Fresh stage (Days 1-2): This stage begins at the moment of death and ends when the bloating of the carcass is observed. Even though autolysis occurs at this stage, gross morphological changes do not occur at this point. The estimation of the time of death by entomological data after 24 hours is more accurate than a medical examiner's estimation based on the soft tissue examination. Insects were seen attracted within the first 10 minutes of death on the carcass, but no egg laying (oviposition) was found during this state. Cellular breakdown occurs during this stage without morphologic alterations. Even though morphological changes and odors are not obvious to humans, the chemicals released from the cellular breakdown attracts insects even in this early stage. (LeBlanc and Logan (2010))

2) Bloated stage (Days 2-7): Putrefaction begins at this stage. Gases produced by the metabolic activities of anaerobic bacteria cause an inflation of the abdomen and the carcass forming a balloon-like appearance during the later part. Arthropod activities combined with the putrefaction processes cause internal temperatures of the carcass to rise. The greatest numbers of adult Diptera were attracted to the carcasses during this stage. By the fourth day, first and early second instar or larval stages Diptera were present. By the beginning of Day 2, several predators of Diptera larvae were also recovered from the carcasses.

3) Decay stage (Days 5-13): Abdominal wall is penetrated, resulting in the deflation of the carcass and ending the bloated stage. The internal temperature rises to 14 degrees above the ambient temperature followed by a drop signifying the end of the decay stage. Decaying odors are high during increased temperatures and drop with the fall in temperature. There is a steady decrease in the weight of the carcass by 10th day. There is a conversion of carcass biomass to dipteran larval biomass. The larvae subsequently depart from the carcass to

pupate.

4) Post-decay stage (Days 10-23): The post-decay stage begins when most of the Diptera larvae leave the carcass, leaving behind bones, cartilage, hair, small portions of tissue, and a large amount of wet, viscous material known as byproducts of decay (BOD). The BOD is the major site of arthropod activity during this stage.

5) Remains stage (Days 18-90+): This stage is characterized by bones with little cartilage remaining and dried up BOD. The transition from post-decay to remains stage is gradual, with declining adult and larval Diptera populations (Joseph et al. (2011), Tullis and Goff (1987)).

The "biological clock" of an insect starts with the invasion of the insect and is stopped by the collection and preservation of the insect from the corpse. Each stage of development of each insect or other arthropod collected from the body represents a distinct interval of time on that clock - hours, days, months, or possibly years. To determine the interval represented, each sample must be fixed in time and development by killing and preserving the specimens (Goff (2001), p. 39). After preservation comes the major task of identifying the specimens. This is a matter of sitting for long hours over a dissection or compound microscope looking at various structures and counting eyes, wing veins, and hairs or bristles on various parts of the insects' bodies (Goff (2001), p. 41).

Insects that are attracted to a corpse begin invading via the body openings. The eyes are the first entry point as they are composed of majority muscles and are easily accessible. They are also moist. Afterwards the nose, mouth, ears, anus, and genitals, if exposed, are invaded in that order if the body has no open wounds or external bleeding. Since flies prefer moist over dry openings, bodies with open wounds or external bleeding attract a higher number of insects as there are more areas available to occupy. Old wounds on the body do not pose a similar attraction because old wounds dry up as they heal. The female flies lay their eggs in these moist areas which then hatch and move into the body, usually within 24 hours.

There are six distinct stages of development for a fly. Each stage takes a known amount of time, depending on the temperature and availability of food. Temperature is especially important since insects are cold-blooded, meaning their metabolic rate increases as the temperature rises and the duration of development decreases, and vice-versa. Therefore, the colder months would see a decrease in insect activity while in the warmer months, rate of activity would increase.

The female adult fly that is attracted to a body will lay her eggs which then hatch into maggots, which are the larva that undergo three stages of development before entering the puparium stage. The first stage of the maggot is called the first instar larva in which its external cuticle is composed of chitin for flexibility and protection from the environment. Although its chitin cuticle is flexible, it limits the size of the maggot. Therefore, the maggot sheds its cuticle or "skin," producing new and larger "skin" as it grows. The second stage of the maggot is known as the second instar larva and the third stage is known as the third instar larva. The first instar stage is the shortest, followed by the second and then the third for length. The third instar stage can be divided into two parts: the active feeding stage and the post-feeding/wandering stage. Maggots feed actively on a corpse and keep to a tight mass of maggots to stay warm. When the maggot reaches its maximum size, it stops feeding and enters the next developmental stage. The post-feeding/wandering stage is the longest period of maggot development as the maggot's gut begins to empty as food is digested and it prepares to enter the puparium stage. It decreases in length and moves away from the corpse to a drier area safe for pupation. Once in the puparium stage, its cuticle changes color to a deep reddish brown which is not attractive to predators and is resistant to heat, cold, desiccation, and moisture. While in its pupa form, the insect undergoes metamorphosis into an adult fly which takes 6-14 days (Goff (2001), p. 54). When the adult fly is ready to exit its pupal case, it is soft and pliable with a soft and light colored cuticle and wrinkled, collapsed wings. Over a period of time, the cuticle hardens and the fly assumes its adult coloration, expands its wings, and becomes fully functional. According to Goff, insects and arthropods are not able to compensate for changes in temperature (Goff (2001), p. 56). Therefore, below a certain threshold, insects are too cold to fly and cannot lay eggs or deposit larvae. At 50 °F, development ceases to the point that larvae are still alive but cease development until the temperature rises. Heat speeds up development. The higher the temperature, the faster the developmental rate, and the smaller the size of the adult fly.

Maggots can be used to test for the presence of drugs and toxins in a badly decomposed corpse, which is essential in forensic investigation in determining whether the victim was poisoned. The types of insects in the Palouse region that would be attracted to a corpse (in addition to flies, which were described above) are the Scarabaeidae and Silphidae families. The Scarabaeidae family is often called scarab beetles. The Silphidae family is also known as the burying beetle that colonizes all the four stages of decomposition (fresh, bloated, decay, and dry) (Hatten (2007)).

Damage caused by animal scavenging accelerates decomposition. As the animal disarticulates the remains, consumes soft tissue, and gnaws on the bones, it increases the surface area on which bacteria and insects can thrive. Animals disarticulate corpses from the head downward (with the mandible separating from the skull, and the head from the vertebral column) and from central to peripheral (from vertebral column to limbs) (Clark et al. (1997)).

Is there any difference in scavenging patterns if a corpse is found closer to a populated area as compared to a rural area? This may depend on the accessibility of the corpse to the scavenger. For example, pet owners who died in their own home without being discovered until later have ended up as a meal for their hungry pet (Steadman and Worne (2007)). As decomposition progresses, the corpse is broken down to skin and bones, allowing body parts to be easily disarticulated more individually by scavengers. This happens due to the loss of muscles (flesh) that hold the corpse together. Therefore, as decomposition increases, the likelihood of skeletal remains being individually disarticulated increases as well (Kjorlien et al. (2009)). The decomposition process is delayed at higher latitudes due to limiting factors of microbial activity and lack of soil decomposers. However, animals can still scavenge the corpse and become the major decomposer.

Animal scavenging will usually speed decomposition as the animal tears off limbs or sections of the corpse, exposing more surface area for bacterial decomposition and insect activity. Animal scavenging is considered to have both physical and chemical effects on the corpse. The physical effect is the removal of flesh and bones. The chemical effect is the increase in the speed of the breakdown of the biological material due to enzymes in the animal's saliva and the introduction of bacteria and other microflora and micro fauna by the scavenger. The breach of the normally protective skin layer also contributes to breakdown. There are always unintended consequences to scavenging. Removed body parts by scavengers will be defleshed if there is still flesh left, and the skeletal remains will be gnawed and chewed on. Skeletal fragments are then scattered around the area. Body parts that have been removed by scavengers can still help in the investigation as some removed body parts may be better preserved in different environments or in lesser moisture especially if stored for later consumption. Animals are a significant part of the decomposition process if the corpse is disturbed by scavengers. They alter the process completely and affect the whole of the system.

Does animal size matter in scavenging? Does carcass size matter in scavenging? Small scavengers need to wait their turn to feed while larger ones may use their size and strength to actively drive away other carnivores. Table 4.1 provides the average weight of scavengers in the Palouse region that might play a role in scavenging corpse which could affect decomposition. The types of animals in the Palouse region that might scavenge bodies, from larger to smaller size, are the grizzly bear (*Ursus arctos horribilis*), black bear (*Ursus americanus*), mountain lion (*Puma concolor*), wolverine (*Gulo gulo*), coyote (*Canis latrans*), Canada lynx (*Lynx canadensis*), bobcat (*Felis rufus*), northern rockies fisher (*Pekania pennanti*), and pine marten (*Martes americana*) (Anon. (2016)).

Scavenger	Average weight (lbs)
Grizzly bear	290-600
Black bear	240
Mountain lion	64-220
Wolverine	20-55
Coyote	15-46
Canada lynx	18-24
Bobcat	19
Northern rockies fisher	8-12
Pine marten	2-9

Table 4.1: Average weight of scavengers in the Palouse

CHAPTER 5

Environmental Effects on the Palouse Region on Decomposition

This chapter puts together data from Chapters 3 and 4 to predict how decomposition, insect activity, and animal scavenging would take place in the Palouse region during the different seasons. The warmer months tend to encourage any decomposition, insect activity and animal scavenging activity if conditions allow for any to happen, whereas the colder months would see a decrease in those activities.

During the winter season in the Palouse region, the temperature gets cold enough for decomposition to grind to a halt or slow severely [see Table 3.3]. In the springtime, the warm temperatures during the daytime would allow decomposition. Based on the temperature data in spring, the average warm temperature reading is approximately 56.7 °F, which could allow slight decomposition while the average cold temperature at about 35.8 °F would cause preservation [see Table 3.3]. Although the warm weather could cause slight decomposition, the acidic soil and moisture in the air, soil (if the body was left in or on soil) and the body itself would form adipocere. However, if the body were left indoors, the warm weather and moisture in the air would allow decomposition to occur. If the body is exposed to oxygen, being left in the open for instance, decomposition would proceed depending on the oxygen levels, while a body being buried with no air flow would undergo preservation. Any clothing or covering on the victim can affect decomposition as well. In the presence of oxygen, the usage of cotton material or plastic bag would still drive the body toward decomposition, while polyester would lead to adipocere formation. In anaerobic conditions, a plastic bag or cotton material would cause body preservation while polyester would cause adipocere formation. Since the average temperature in the fall in the Palouse is about the same as the spring (37.4 °F - 59.1 °F) [see Table 3.3], the corpse would decompose in a similar to manner to that of spring. As the weather is hottest in the summer time, the warmer average temperature of 79.3 °F would cause decomposition, while the lower temperature during the nights at approximately 48.8 °F would cause preservation or slight decomposition [see Table

3.3]. Other factors, such as soil pH and the presence of moisture, oxygen, and clothing, would affect decomposition similarly to the spring and fall.

The average precipitation during the summer months in the Palouse area is 0.050 inches [see Table 3.2]. In the summer time where the average maximum temperature is the highest compared to other seasons, the average precipitation is at the lowest. Given this relationship, humidity in the Palouse area in the summer time would decrease. Lesser humidity could prevent decomposition and cause some degree of mummification during the day when the temperature is the highest. Since the average maximum temperature in the summer in the Palouse area do not reach as high as the maximum temperature in the Arizona-Sonoran Desert, odds of mummification for bodies are unlikely. In the winter months, the average precipitation in the Palouse area is 0.0103 inches [see Table 3.2]. During those months in the Palouse area where the average precipitation is at its highest and its average maximum and minimum temperatures are at its lowest, there will be an increase in humidity. Increase in humidity encourages decomposition or adipocere formation. However, an increase in humidity in the winter months would not cause decomposition as the temperature is below the optimum point for any decomposition to happen. Thus, preservation would occur instead. The average precipitation during the spring months in the Palouse area is 0.077 inches [see Table 3.2] and in the fall, the average precipitation is 0.067 inches [see Table 3.2]. Although the average precipitations for both seasons are not as high as in the winter, both figures are above the average precipitation in the summer. It will be somewhat humid during both seasons which would encourage decomposition or adipocere formation.

Under certain circumstances where corpses are buried or kept in a tightly sealed environment, the corpses would not undergo decomposition due to lack of air (oxygen) which is essential for the survival of aerobic bacteria that can be found on decomposing remains. Although it is more favorable for decomposition to happen in the summer time, the non-existence of air would cause preservation instead regardless of other environmental factors. It is predicted that preservation would happen in the winter time whether the corpse is exposed to air or not. In the spring and fall seasons, decomposition could occur. However, the lack of exposure to air would prevent decomposition of remains and cause preservation.

As for soil pH, the general soil pH in the Palouse area is less than 6.0 which is acidic. The optimum pH for decomposition to be retarded and adipocere formation happen is at pH 5. In the summer time, decomposition is more likely to happen given other environmental factors that are to be accounted for besides soil pH. In the spring and fall seasons, slight decomposition would occur during the day even if the corpse is in contact with soil. While during the night, decomposition process is halted and adipocere formation could occur. In the winter time, the cold temperature would prevent any decomposition or adipocere formation to happen even with the right soil pH for adipocere to form. However, different areas in the Palouse might have a different soil pH reading. More research needs to be conducted in specific places in the Palouse area for a better understanding of the effects of soil pH on decomposition.

The optimal temperature for insect larvae to have a normal development is at 50 °F. If the temperature falls below 50 °F, insect development ceases to the point where the larvae are still alive but stop developing until the temperature rises. The higher the temperature, the more quickly the larva develops. However, its size as an adult fly will be compromised as quicker development does not allow for normal rate of development. During the winter season in the Palouse region, insect activity would most likely decrease as the average temperature is approximately 20 °F [see Table 3.3] lower than the optimal temperature for any development to happen. In the spring and the fall seasons, the possibility of insect activity is higher than in the winter given the approximated average temperature is between 35.8 °F - 59.1 °F [see Table 3.3]. Development would proceed to take place during the warmer days in both seasons where average temperature is above 50 °F and then come to a halt when the temperature falls below the optimum temperature for development. Insect activity usually happens more frequently in the summer season where the average temperature is 48.8 °F - 79.3 °F [see Table 3.3]. Larvae will then continue with their development that had ceased during the colder months in the Palouse region.

When it comes to scavenging, a scavenger with a higher body mass would have the first priority as it could fight off smaller-sized scavengers unless it is outnumbered by smaller-sized scavengers by a good number. For example, a grizzly bear that comes across a pack of coyotes scavenging a corpse will have to fight off the pack in order to scavenge the corpse. Although the grizzly bear is approximately 10 times heavier in weight compared to a coyote [see Table 4.1], chances of the pack of coyotes leaving the grizzly bear to scavenge the corpse alone is quite unlikely. The list of scavengers in the Palouse region are as follows starting with the grizzly bear having the highest average weight likely having first priority when it comes to scavenging follow by the black bear, mountain lion, wolverine, coyote, Canada lynx, bobcat, northern rockies fisher, and pine marten [see Table 4.1]. The amount of flesh and bone that is left to be scavenged by the time the lowest average weight scavengers gets ahold of the corpse might be close to none. If the corpse is in an early state of decomposition, the possibility of the earlier scavengers running off with limbs or other parts of the corpse is lower. This means a higher chance of being able to collect a complete skeleton or corpse. However, a corpse that is more decomposed will enable scavengers to run off with limbs or bony parts as it tends to be a preferred habit of scavengers, at least the smaller sized ones, to take its food to someplace hidden or safe before consuming it. This habit would allow them to consume their food without worrying about other scavengers showing up to fight over the food. During the colder months, scavengers that are larger are usually in their hibernation period. In addition, the decomposition process decreases when the temperature drops, which mean lesser attraction from insects and scavengers. Therefore, scavenging activity in the Palouse region would be reduced to little or none in the winter months.

CHAPTER 6

Conclusion

The purpose of this paper is to be able to establish a timeline in decomposition process of a human body in the area around the Palouse region. Warmer months tend to accelerate decomposition which includes insect activity and animal scavenging while the colder months have the tendency to inhibit or decrease decomposition. However, only a general timeline can be established here instead of a more specific timeline due to the environmental conditions in other studies not matching the exact conditions in the Palouse. Further studies specific to the Palouse region need to be carried out to better understand and generate a more exact timeline for human decomposition, as well as further studies on the effects and behavior of insects and scavenger species in the Palouse region area.

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Appendix A: Temperature and Precipitation Tables

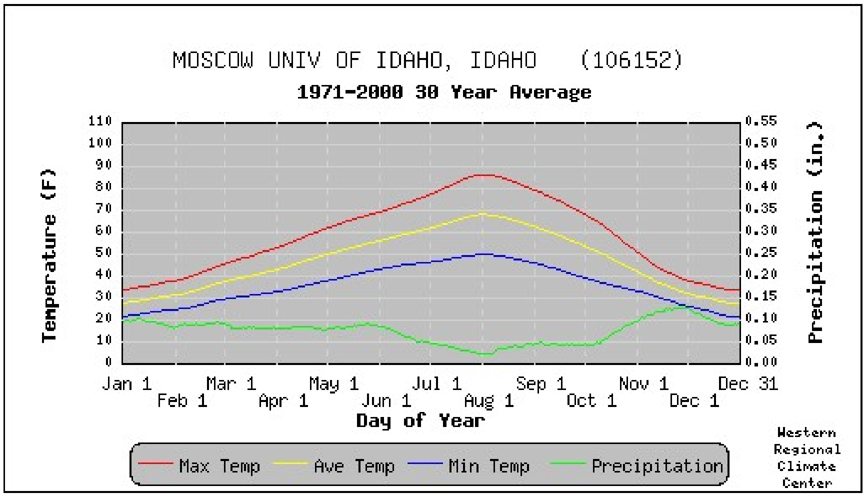

Figure 6.1: 1971-2000 temperature and precipitation for Moscow University of Idaho, Idaho

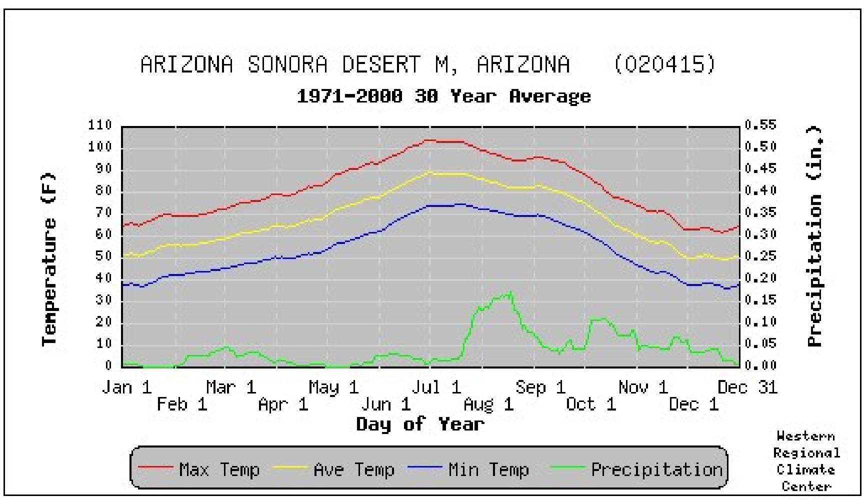

Figure 6.2: 1971-2000 temperature and precipitation for Arizona Sonora Desert M, Arizona

Table 6.1 shows the average maximum and minimum temperature in the Palouse region from 1893-2005 which is used to calculated the average maximum and minimum temperature in Table 3.3 for each season in the area during that period of time. Figures 6.1 is the recorded average temperature and precipitation for the Palouse region (based on Moscow University of Idaho, Idaho) from 1971-2000. Figure 6.2 is the recorded average temperature and precipitation for the Arizona Sonora Desert M, Arizona from 1971-2000. Data from Figures 6.1 - 6.2 are used to calculate the average precipitation in inches for the Palouse region in Table 3.2.

Month	Average max in °F	Average min in °F
December	36.3	25.0
January	34.8	22.6
February	40.2	25.9
March	47.6	30.6
April	57.0	35.6
May	65.4	41.2
June	72.6	46.3
July	82.9	50.3
August	82.5	49.7
September	72.9	44.1
October	60.0	37.4
November	44.4	30.6

Table 6.1: Average maximum and minimum temperature in the Palouse region from 1893-2005