4-12-2010

Differential Decomposition Patterns Of Human Remains In Variable Environments Of The Midwest

Melissa A. Pope
University of South Florida

Differential Decomposition Patterns Of Human Remains In Variable Environments Of The Midwest

by

Melissa A. Pope

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts
Department of Anthropology
College of Arts and Sciences
University of South Florida

Major Professor: Erin Kimmerle, Ph.D.
Lorena Madrigal, Ph.D.
David Himmelgreen, Ph.D.

Date of Approval:
April 12, 2010

Keywords: indoor environments, forensic anthropology and taphonomy, postmortem interval, human rights, time since death estimation

Dedication

I would like to dedicate this paper to my parents, Annina and David Pope, whose support and guidance have pushed me to achieve my dreams.

Acknowledgements

I would like to thank Erin Kimmerle, Ph.D., for her mentorship and guidance throughout the thesis writing process. I would also like to thank my committee members, Lorena Madrigal, Ph.D. and David Himmelgreen, Ph.D., who have been integral to my education as an anthropologist, and for their thoughtful advice on my thesis manuscript. The Nebraska Institute of Forensic Sciences, Inc. deserves special recognition for the provision of an internship opportunity, access to their data, and funding for my research. Within this organization, special thanks go to Cory Avery and Julie Nickel, who provided me with infinite assistance for data collection. I would also like to thank Timothy Huntington, Ph.D. for advising me on sources of outside data. I am especially indebted to Dr. Matthias Okoye, who provided me with an opportunity to do research and to learn from his pathology practice. A warm thank you is extended to the Okoye family, who opened their home and their hearts during my stay. Lastly, I am especially grateful for Casey C. Anderson, who assisted with data collection and offered advice throughout the writing process. Thank you.

Table of Contents

List of Tables

List of Figures

Differential Decomposition Patterns of Human Remains in Variable Environments of the Midwest

Melissa Ann Pope

ABSTRACT

Where do people die alone when they remain undiscovered for extended periods of time? Estimation of the postmortem interval (PMI) is critical to reconstructing the events surrounding a person's death and this is an area in which forensic anthropologists have played a leading role. This thesis applied an anthropological framework that takes a comprehensive approach to analyzing the demography of unaccompanied deaths, the relationships and timing of decomposition in multiple depositional contexts, and created a model for the prediction of accumulated degree days (ADD) for bodies within enclosures.

While there have been extensive experimental and case study reviews on decomposition in outdoor environments, very little data exist for enclosed spaces. A retrospective analysis of 2003-2008 Nebraskan autopsy records demonstrates that most people dying alone are within their homes. Of the 87 forensic cases reviewed, 69 unaccompanied deaths occurred within enclosed environments. The value of retrospective studies in combination to experimental research is that the large number of variables that affect decompositional rates may be explored in a natural context.

Multivariate models put emphasis on the dynamics of decompositional change and comprehensively address death and decomposition within an anthropological framework.

For enclosed depositions, the PMI ranged from 1 – 66 days (*n= 64,* $\overline{X}$ *=4.84, s.d.=9.1037)* and the ADD ranged from 0 – 786 ADD (*n=64*, $\overline{X}$ *=67.43, s.d.=120.275)*. Bass' (1997) model for outdoor surface decay was found to be an adequate predictor of the PMI for this sample (*r=0.829, n=64, p≤0.000*). A relationship was identified between ADD and stages of decomposition (*r=0.585, p≤0.000, n=64*). A *Nonparametric Kruskal-Wallis test* revealed that there were significant differences in ADD among stages of decay. These results provided support for the prediction of ADD as a measure of the rate of decomposition.

Relationships among ADD and multiple intrinsic, extrinsic and epidemiological variables were identified and considered for a multiple linear regression model. Variables selected by the model included: decomposition odor, use of air conditioning/heat, marbling, brain liquefaction, and mummification. The model was found to account for 95.2% of the variation in ADD (*Adjusted* R^2 *=0.952*; *F=40.807, df=5, 5 and p≤0.000*).

Chapter 1

Introduction

In U.S. society it is not uncommon for people to die alone without their loved ones knowing of the loss. These cases inevitably lead to questions about the circumstances surrounding the death. Diligent scrutiny and thorough investigation of the incidents surrounding the person's death are necessary to reconstruct the context of the death event. Biological anthropology becomes critical in this process as methods are applied within the medicolegal setting to aid in the identification of human remains and perimortem trauma, which is relevant for determining the cause and manner of death and estimating the time since death. An accurate estimation of the time frame from when the person died until he or she was discovered (the postmortem interval, or PMI) is essential to a successful identification and accurate reconstruction of the death event (perimortem interval), particularly in cases of homicide where the postmortem interval is critical to establishing investigative leads and contributing towards case solvability.

When an organism dies, its body endures alterations as a result of the various processes acting upon it. Taphonomy may be understood as everything that affects an organism from the time of its death to the time that it is discovered, the reconstruction of these events, and the reconstruction of the conditions of its death (Haglund and Sorg 1997c:13). Determining these forces, their sequence, and effects on the remains is fundamental to estimating the time range from when a person died to when he or she was discovered. Estimation of the postmortem interval is an integral part of reconstructing the events surrounding a death (perimortem), and is often studied through examination of rates of soft tissue decay and skeletonization (Dirkmaat and Adovasio 1997). Research on this topic is environment-specific, and consequently there are many gaps in what the scientific community knows about decomposition and the postmortem interval. There is a great need for research into taphonomy that accounts for environmental variation, as research in this area is very limited in scope and geographic origin (i.e., Bass 1997; Galloway 1997; Galloway *et al.* 1989; Komar 1998; Mann *et al.* 1990; Rodriguez and Bass 1985).

Most data on the use of taphonomy as a measure of the postmortem interval comes either from case studies or experimental research on select environments, such as Hawaii and Tennessee (i.e., Goff 1991; Micozzi 1986; Rodriguez and Bass 1983,1985; Schroeder *et al.* 2002; Steadman and Worne 2007; Vass *et al.* 1992; Voss *et al.* 2007). Experimental studies of decomposition primarily have been conducted in an outdoor surface environment in few geographical areas, and the timetables produced are not necessarily representative of the changes seen in bodies found in differential depositional contexts (i.e., Rodriguez and Bass 1983; Vass *et al.* 1992). While experimental studies are useful for documenting and analyzing the process of decay, their environments are artificial and cannot adequately address the range of variation in decomposition that anthropologists encounter in casework. Specifically, there is a paucity of research into the factors that affect the rate of decay for bodies that decompose in sheltered environments (i.e., Galloway 1997; Galloway *et al.* 1989; Goff 1991; Schroeder *et al.*

2002). Moreover, while both case study and experimental research designs are conducive for an analysis of decomposition in variable environments, both are characterized by small sample sizes, which precludes the use of statistical models with predictive power and potential error rates.

While retrospective studies on human decay have been few in number, they have made important contributions to the development of decomposition research (i.e., Galloway 1997; Galloway *et al.* 1989; Goff 1991; Komar 1998; Manhein 1997). The many environmental factors involved in the decomposition process cannot always be controlled or even accounted for, and this is especially true for studies that are conducted retrospectively. Yet the benefit of the retrospective study is that the extrinsic or environmental factors are representative of what might be encountered in an actual death scenario. The most important environmental factor is the temperature accrued over the postmortem interval (accumulated degree days, or ADD). A retrospective study can incorporate local temperature data into a predictive model for decay rates (i.e. Megyesi *et al*. 2005).

This thesis applied an anthropological framework that takes a comprehensive approach to the many variables involved in unaccompanied deaths and decomposition rates. Extrinsic, intrinsic and epidemiological variables were considered. Epidemiological variables were those factors that reflect human behavior in some way and that were specific to the context of a person's death, such as manner of death. Extrinsic variables were environmental influences, such as temperature. Intrinsic factors were biological characteristics of the decedent, such as decompositional changes or age.

This thesis also employed a protocol that operationalized the anthropological framework and that could be applied to a variety of settings. Protocols are essential to scientific credibility because in legal cases one must meet evidentiary standards in court by demonstrating that methods used were justifiable (Christensen and Crowder 2009; Kimmerle and Baraybar 2008; i.e., *Daubert v. Merrell Dow Pharmaceuticals, Inc.* 1993; *General Electric Co. v. Joiner* 1997; *Kumho Tire Co. v. Carmichael* 1999). Therefore, accuracy and validity of estimates must be well understood. The retrospective study presented in this thesis used larger sample sizes and took into account the environmental limitations of an enclosed location. A large sample size allowed for quantitative methods to be used to make powerful generalizations as a meaningful contribution towards decomposition research for enclosed settings. The purposes of this study were to: investigate the demography of unaccompanied deaths; identify and describe decomposition within each context; quantify the relationships among extrinsic factors, epidemiological variables and decompositional changes into a predictive model for the estimation of the time since death for enclosed spaces.

First, this thesis explored the demography of people who died alone and remained undiscovered long enough to undergo decomposition. To achieve this purpose, this thesis tested the following:

- The relationship between manner of death and sex.
- The relationship between manner of death and age.
- The relationship between cause of death and sex.
- The relationship between age range and cause of death.

- The relationship between drug or alcohol related deaths and suicidal or accidental and natural deaths.
- The relationship between traumatic deaths and homicidal and suicidal manners of death.
- Described the age, sex, manners of death and causes of death for near-surface, subsurface, aquatic and enclosed contexts.
- The difference in the postmortem interval among manners of death.

The second objective of this study was to test decomposition rates that were identified within each context by:

- Testing the reliability of Bass' model as applied to all contexts combined.
- Describing the identified factors that influence the rate of decay for near-surface, subsurface, aquatic and enclosed contexts.
- Describing the postmortem interval and accumulated temperature over time for remains found in near-surface, subsurface, aquatic and enclosed contexts.

Finally, for enclosed spaces this thesis quantified decompositional changes and investigated the relationships and timing of the many intrinsic, extrinsic and epidemiological variables into a predictive model for the estimation of the postmortem interval. Specifically, this analysis:

- Tested whether bodies were more likely to decompose before discovery in the summer and spring than in the fall and winter, and demonstrated that seasons can be used to approximate temperature.

- Showed that the data reflected variability in decay and retrospective data were appropriate for the study of decay. It was also important to establish that PMI and ADD are appropriate measures for the rate of decay.
    - Tested for relationships between the postmortem interval, accumulated temperature over time and stages of decomposition created by Bass (1997). This test demonstrated that ADD was an appropriate measure for decompositional change.
    - Tested the reliability of Bass' (1997) model as applied to the enclosed setting. This test showed how well a context-specific standard can be applied to novel environments. This relationship also shows that the retrospective data showed variability in decay and were appropriate for the study of decomposition.
    - Tested for differences in the postmortem interval and accumulated temperature over time among the stages of decay created by Bass (1997). Differences in PMI and ADD among decay stages demonstrated that the sample possessed variability in decay rates and that ADD were an appropriate measure for decomposition.
    - Determined the likelihood of the presence of certain taphonomic effects within and after the first week of the postmortem interval. This helped to determine and quantify when individual taphonomic effects were more likely to be displayed. This also suggested that early postmortem changes occurred later in the postmortem interval for enclosed depositions, when

compared to bodies that decomposed in outdoor Tennessee (Bass 1997; Galloway *et al*. 1989).

- Determined which intrinsic, extrinsic, burial and epidemiological variables had a strong relationship with the postmortem interval and accrued temperature over time. This helped identify variables that could be useful in predicting the accrued temperature over time.
- Built a *linear multiple regression* that predicted the accrued temperature over time for bodies that decomposed within enclosed settings.

The long-standing focus on taphonomic research in anthropology places forensic anthropologists in a unique position to interpret the biological, cultural, behavioral, and ecological forces that affect a body after death. The anthropological framework employed in this thesis was instrumental in the development of a decomposition model that quantified the rate of decay for the estimation of the postmortem interval and produced a measure of standard error.

Chapter 2

Literature Review

Forensic Taphonomy Defined

Taphonomy has a long-standing tradition in anthropology, but has traditionally fallen within the purviews of archaeology, paleoanthropology, paleontology and paleoecology (Behrensmeyer and Hill 1980a; Gifford 1982; Henke and Tattersall 2007; Lyman 1994; Lyman 2002). Haglund and Sorg (1997c:13) define taphonomy as " the study of postmortem processes which affect (1) the preservation, observation, or recovery of dead organisms, (2) the reconstruction of their biology or ecology, or (3) the reconstruction of the circumstances of their death." Paleontologists and paleoanthropologists are concerned with taphonomy as it relates to the processes that incorporate deceased organisms into the geological record (Grupe 2007; Lyman 1994). The goal of paleoecology is to understand past ecosystems by studying fossil assemblages as evidence of relationships among extinct faunal populations and between past populations and their physical environment (Behrensmeyer and Hill 1980b; Lyman 1994). Archaeologists have similarly holistic goals, but their focus is on the interface between hominids and their environments (Lyman 1994). Paleoanthropologists are concerned with environmental reconstruction as it pertains to hominid evolution and speciation of primates (Grupe 2007; Henke 2007). Further, Henke (2007:28) asserts that archaeology focuses on cultural remains and is a social science, whereas paleoanthropology focuses on biological remains and is a natural science.

Forensic anthropology has embraced both approaches as a natural extension to the forensic tasks of reconstructing the events surrounding a person's death, and distinguishing between perimortem injury and postmortem modification (Haglund and Sorg 1997b,c). Forensic anthropology and bioarchaeology have been referred to as "symbiotic and even synergistic (Saul and Saul 2002:72)." Both disciplines are interested in analyzing associations among artifacts and context as a means of inferring past events that led to the deposition of a body (Dirkmaat and Adovasio 1997; Scott and Connor 1997). Analogous to bioarchaeologists and paleoanthropologists, forensic anthropologists attempt to discover behavior in past events by evaluating taphonomic factors and reconstructing the relationship between a body and its surroundings (Dirkmaat and Adovasio 1997; Grupe 2007; Scott and Connor 1997; Saul and Saul 2002).

Unlike paleoecology or paleoanthropology, forensic taphonomy is most interested in discerning phenomena associated with the death event (perimortem interval) from those that were incurred during the postmortem period (Haglund and Sorg 1997b). Forensic anthropologists want to perform a full reconstruction, which requires knowledge on what happened to the person up until the death event, during the death event, and since the death event. Forensic anthropology departs from the archaeological or paleoanthropological approach in that its focus tends to encompass the earliest spectrum of postmortem changes as well as skeletonization and disarticulation processes (Haglund and Sorg 1997b; Saul and Saul 2002), whereas paleoanthropologists tend to focus on skeletal and fossil remains (Grupe 2007). Even when a body has been skeletonized before recovery, understanding the processes of soft tissue decay can aid in interpreting the positional context of a set of remains by ruling out taphonomic artifacts (Roksandic 2002). Consequently, soft tissue decomposition is an essential consideration in forensic taphonomy (Haglund and Sorg 1997b).

Forensic taphonomy is also unique in that its focus tends to be on the individual, rather than on the population or the species (Haglund and Sorg 1997c:14). Although forensic anthropologists, archaeologists, paleoanthropologists and paleontologists are all looking at unique specimens that may not represent the population from which they were derived, the latter three are interested in reconstructing a community or an ecosystem, respectively, whereas forensic anthropologists are primarily concerned with reconstructing the events explicitly associated with the decedents' death event (Behrensmeyer and Hill 1980a; Henke 2007; Lyman 1994; Haglund and Sorg 1997c). These shifts in attention are reflected in the theories and models constructed to interpret taphonomic occurrences.

This study used an innovative anthropological framework for decomposition research (Table 2.1). The anthropological model is holistic in that the cultural factors of who dies alone were investigated in addition to the extrinsic and intrinsic factors related to the rate and extent of taphonomic change. This framework was meaningful because the key issue is not only that people die alone, but also that enough time passes as to allow decomposition before discovery. Extrinsic factors are those environmental forces that traditional taphonomists refer to as taphonomic processes, such as changes in temperature and access by insects. In contrast, intrinsic factors are those biochemical properties inherent to the individual, such as weight and the degree of biological health. Intrinsic factors also encompass the decompositional changes of the body, or what taphonomists call taphonomic effects. While these forces are fundamental to demystification of the process of decay, they say nothing of the sociocultural variables that presuppose a body remaining undiscovered long enough to necessitate a reconstruction of the peri- and postmortem events.

For this thesis, epidemiological factors were defined as those variables that reflected behavior in some way and that were specific to the context of a person's death, such as manner of death. The epidemiological approach in forensic anthropology investigations has previously been applied to trauma analyses in cases of human rights violations (Kimmerle and Baraybar 2008) and to populations at risk for remaining unidentified in the U.S. (Kimmerle *et al*. 2009). Within the context of a human rights investigation, "(t)he age and sex distribution of victims, the ratio of wounded to killed, patterns among civilians versus soldiers, and the risk to victims provides evidence of the type of crime committed (Kimmerle and Baraybar 2008:6)." For war crimes investigations, establishing who the victims were is critical to demonstrating illegal action and intent. This approach was well suited to the study of unaccompanied expirations because it accounted for who the decedent was and how the person's identity played a role in the circumstances of his or her death. The epidemiological approach allowed for the relationship between a person's identity and other considerations related to the nature of hers or his solitary death to be factored into the estimation of time since death. It was herein adopted and applied as it provides explanatory power for who is at risk of dying alone and going undiscovered. On a more practical level, those cultural and demographic parameters are valuable to pursuing leads in medicolegal investigations of death. Through the incorporation of extrinsic, intrinsic and cultural factors, this model became a way to approach the study of isolated deaths within an anthropological context where the biological and social variables worked together, making this a unique and comprehensive model for forensic investigations.

Table 2.1—Anthropological Model for Decomposition.

Factors	Variables	Specific Characteristics
1. Intrinsic (Biological)	• Biological Profile	• Age • Sex • Ancestry • Weight
	• Taphonomic Effects	• Biochemical Factors (i.e., rigor, skin slippage, bloating, marbling) • Decomposition Stage (Bass 1997)
	• Cause of Death	• Trauma • Drugs/Alcohol • Natural/Heart Disease
	• Injuries	• Presence and degree
2. Extrinsic (Environmental)	• Context	• Outdoor surface (i.e., woods, roadside) • Near/subsurface • Submerged (i.e., lake)
	• Time (PMI)	
	• Natural Environment	• Temperature (ADD) • Humidity • Insects
3. Epidemiological /Cultural	• Manner of Death	• Natural • Accident • Homicide • Suicide • Undetermined
	• Burial Factors	• Containers (i.e. blanket, carpet) • Deposition Surface
	• Clothing	• Degree of body coverage
	• Location	• Indoor (i.e., hotel, bedroom, bathroom)

Anthropological Research and the Judicial System

A fundamental concern that sets forensic anthropologists apart from paleontologists, paleoanthropologists, or other biological anthropologists is the issue of whether anthropological evidence will be considered admissible in court. There are several major Supreme Court cases and one rule put into action by Congress that have produced a framework for admissibility of expert testimony: *Frye v. United States* (1923), *Federal Rules of Evidence* (1975), *Daubert v. Merrell Dow Pharmaceuticals, Inc.* (1993), *General Electric Co. v. Joiner* (1997), *Kumho Tire Co. v. Carmichael* (1999).

The *Frye* case set the initial precedence for scientific testimony, stating that evidence must be generally accepted by the scientific community in order to be considered admissible in court (Christensen 2004:427; Christensen and Crowder 2009:1212; Grivas and Komar 2008:771). The *Federal Rules of Evidence* (FRE) was later established by Congress to provide governance over evidentiary standards. Specifically, FRE Rule 702 concentrated on the issue of expert testimony. FRE Rule 702 placed emphasis on qualification of the expert involved. However, the FRE Rule 702 did not address the general acceptance policy stated in *Frye*, and this resulted in inconsistencies in how courts evaluated expert testimonies (Christensen 2004; Grivas and Komar 2008).

In the *Daubert* trial, the courts determined that the FRE Rule 702 replaced *Frye* for the evaluation of expert evidence (Christensen 2004; Christensen and Crowder 2009; Grivas and Komar 2008). The *Daubert* case placed responsibility on judges to ensure the "relevance and reliability of the scientific testimony (Christensen and Crowder

2009:1212)." The Supreme Court produced five guidelines (The *Daubert* factors) to assist judges in the evaluation of expert testimony, two of which emphasize the need for reliable research practices with known or potential error rates (Christensen 2004; Christensen and Crowder 2009; Grivas and Komar 2008). The *Joiner* case stressed the close relationship between methods and conclusions, and placed importance on the need for research practices that are reflexive and relevant to the case at hand (Christensen and Crowder 2009:1212-1213; Grivas and Komar 2008:772-773). The *Kumho* case succeeded in clarifying that the *Daubert* guidelines applied to all expert testimony. Collectively, the Supreme Court rulings and the FRE have established the criteria for what anthropological (and other) evidence may be admitted into court.

The Supreme Court cases and the FRE resulted in an explicit push within the forensic anthropology community to quantify anthropological methods and produce potential or known error rates that meet the *Daubert* standards (Christensen 2004; Christensen and Crowder 2009; Ross and Kimmerle 2009). The trend towards quantified methods and meeting the standards for judicial admissibility has been reflected in recent publications (i.e., Christensen 2005; Kimmerle and Jantz 2008; Konigsberg *et al.* 2006, 2008; Rogers 2005; Rogers and Allard 2004; Skinner *et al.* 2003; Steadman *et al*. 2006). Recently, the National Academy of Sciences submitted a research report (NRC report) to the U.S. Department of Justice (National Research Council 2009). The quality of forensic research admitted into legal proceedings was evaluated and recommendations for improvements were made (National Research Council 2009). Under "Recommendation 3," the NRC report stated that:

> "Research is needed to address issues of accuracy, reliability, and validity in the forensic science disciplines…[There is a need for] (t)he development and establishment of quantifiable measures of the reliability and accuracy of forensic analyses…Studies of the reliability and accuracy of forensic techniques should reflect actual practice on realistic case scenarios…[Research should focus on] (t)he development of quantifiable measures of uncertainty in the conclusions of forensic analyses (National Research Council 2009:22-23)."

The scrutiny of forensic methods has substantial implications on future cases where anthropological evidence may play a role in judicial proceedings. Estimation of the postmortem interval is a vital component of anthropological testimony. Although there has been expression of misgivings towards the ability to accurately quantify such complex processes as taphonomy (Grivas and Komar 2008:773-774), it is critical that forensic anthropologists are aware of admissibility criteria and that they incorporate appropriate research methods to meet the guidelines established by the Supreme Court (Christensen 2004; Christensen and Crowder 2009; Kimmerle and Jantz 2008). Therefore, theory-driven and quantified decomposition research that uses appropriate methods for estimation of the postmortem interval is essential for the growth of forensic anthropology.

Taphonomic Theory and Methodology

The Basics

Before taphonomic theories can be applied to medicolegal death investigation, one must comprehend the nature and relationships between the surrounding environment and a given set of remains. Lyman (1994:35) wrote, "(a) first step to model building involves understanding the basic structure of taphonomic processes and effects." A major goal of traditional taphonomic endeavors is to be cognizant of the taphonomic bias so that the original environmental context can be better analyzed (Gifford 1982). In addition, taphonomic processes "are essentially ecological in nature and operation" and can therefore be informative of the environment (Gifford 1982:485). For these reasons, those who are interested in reconstructing the events prior to, during and after a death event must have knowledge of these processes (Gifford 1981; Lyman 1994).

Lyman writes that "taphonomic histories" begin with the death of an organism and are derived from analysis and interpretation of the underlying geological, biological and cultural processes that modify a carcass (1994:34). Because "taphonomic processes are both *historical* and *cumulative* (Lyman 1994:40)," a good actualistic research strategy is to study processes temporally and to establish normal sequences of events (Gifford 1982). These processes are dependent on the environmental and cultural ingredients that were present when the body was deposited, such as vegetation, climate or hunting practices (Grupe 2007; Lyman 1994). Taphonomic processes interact with a set of remains over time and leave effects that can obscure their original context, but they are also informative of that original context (Grupe 2007:243; Lyman 1994, 2002). Lyman

(1994:35) wrote: "(t)he objects in a site, their frequencies, physical attributes, spatial loci and associations, and geological and cultural associations are all that are observable in the fossil record."

The nature of paleoecological work is to use fossils to understand the interworking of a past ecosystem and to place a certain ecological setting within the broader context of evolution (Behrensmeyer and Hill 1980a; Gifford 1982; Grupe 2007; Lyman 1994). Unlike ecologists who can observe current phenomena, paleoecologists cannot use the same methods for deriving information that an ecologist would use. The process of fossilization occurs under very unique conditions, and consequently fossils do not represent populations (Behrensmeyer and Hill 1980b; Grupe 2007). Rather, fossils are small, isolated clues that can only be interpreted by tracing the specimen back through time. Hence, paleoecologists often invoke the methodologies of uniformitarianism and actualism (Gifford 1982; Lyman 1994).

Traditional Methodology

Uniformitarianism is an overarching principle that was founded within geology and has been largely attributed to the work of Charles Lyell, although the concept has changed over time (Gould 1965, 1979; Lyman 1994). Gould (1965, 1979) has taken this umbrella term and dissected out its multiple meanings, arguing that uniformitarianism has two parts: the theory and the methodology (also see Lyman 1994:47).

The theory that is specific to geology is coined "substantive uniformitarianism," and consists of: "gradualism," where processes at work have been the same in *rate* over time and accumulate to produce large effects; and “nonprogression,” where change occurs cyclically, so that over time the earth remains the same (Gould 1965, 1979:126-127). Lyman equates substantive principles with “configurational properties, because they are context specific, are historical and mutable (1994:52).” Gould argues that substantive uniformitarianism “has not withstood the test of new data” and is “transformed into an *a priori* assumption, stifling to the formulation of new hypotheses which may better explain certain data (Gould 1965:226).” Therefore, for the purpose of this discussion, substantive uniformitarianism is only of historical interest in its giving rise to methodological uniformitarianism, and for its occasional conflation with methodological uniformitarianism.

Methodological uniformitarianism is a scientific approach that was derived from geology but is not contained to it, and also consists of two parts (Gould 1965:226, 1979).

> First, there is “uniformity of law…natural laws are invariant in space and time (Gould 1979:123-124). Lyman equates this with “immanent properties…those immutable physical and chemical reactions that occur with predictable results regardless of spatiotemporal context (1994:52).” Secondly, there is “uniformity of process (actualism)…ascribe past results to causes now in operation (Gould 1979:125-126).”

Methodological uniformitarianism is useful for historical sciences and has been adopted by paleoecology and archaeology because the past cannot be empirically observed (Lyman 1994). One can view modern effects and infer a relationship to modern processes (induction), then extend this inference so that similar past effects may be explained by similar processes that were at work in the past and are currently at work today (Gould 1979). Methodological uniformitarianism is thus analogous to actualism, where actualism is the operation of analyzing evidence that currently exists (i.e., a fossil) and looking at processes that currently occur, and using them to infer information about the taphonomic history of that evidence (Gifford 1982; Gould 1965, 1979; Lyman 1994). Consequently, methodological uniformitarianism or actualism has become an important procedure in archaeological and paleoecological taphonomy. This is because actualism allows taphonomic artifacts from the past to be interpreted as results of processes that are currently occurring (Gifford 1982; Gould 1965, 1979; Lyman 1994). Gifford (1982:476) writes: "(f)or taphonomy, as in other branches of historical science, study of the present is the key to investigation of the past." The anthropological model and protocol used for this thesis was designed to operationalize actualistic methods. The protocol is designed for data collection on the context of discovery, which allows for inferences to be made on the PMI and perimortem circumstances.

Theoretical and Methodological Problems

Paleoecologists rely loosely on ecological theories to explain fossil assemblages (Lyman 1994). However, within paleoecological studies, there has been no unifying theory or method to guide taphonomic research questions, and a general lack of theoretical discussions within the field (Gifford 1982). For anthropological estimations to be admissible under the *Daubert* standard, methods must be theory guided (Rogers 2005:494). However, forensic taphonomic research has also been notoriously idiosyncratic and lacking in covert use of theory. Unsurprisingly, there has been limited interaction between traditional taphonomic studies and forensic anthropology (Haglund and Sorg 1997b).

Perhaps the restricted interface between traditional taphonomy and forensic anthropology is due in part to forensic anthropology's emergence from medicolegal necessity. Like other realms of forensic science, forensic taphonomy is embedded within a medicolegal context, has a practical conception, and is inherently an applied science (Haglund and Sorg 1997b; Nordby 2002; Roksandic 2002; Ross and Kimmerle 2009). It is conceivable that the practical realm in which forensic taphonomy is seated has inhibited the building of theoretical paradigms and application of rigorous research strategies (Ross and Kimmerle 2009:479-480). The medicolegal focus from which it was founded creates a unique standpoint that resonates as practical application in forensic anthropologists' approach to taphonomy, law, forensic science, trauma and other anthropological evidence.

Nordby (2002) has likened the theoretical development of forensic taphonomy to that of early developments in medicine and pathology. Both fields of study arose from practical concerns and were initially devoid of theory. Like the processes under investigation in taphonomy, factors involved in disease processes have complex interfaces that cannot fit neatly within one theory or model. Rather, multiple theories and models must be invoked in unique combinations to explain various pathological (or taphonomic) phenomena (Nordby 2002). Nordby (2002:39) deliberates: "(w)e may not yet have firmly established the science of forensic taphonomy, but it does not follow that it is unscientific—its developing methods and history parallel those of now recognized and trivially accepted theories of disease." Current models in forensic taphonomy are highly idiosyncratic and are not reliable when applied to new cases but these case-specific models are a necessary initial step in the development of a scientific discipline.

Lyman (1994:463) wonders if it is even possible to create a broad-ranging theory for taphonomy. He contrasts the explanatory power of neo-Darwinian theories with that of taphonomic theories. Lyman points out that within neo-Darwinian theories a lineage finds "*ultimate causal explanation*," whereas taphonomic studies remain particularistic and atheoretical (1994:464). Many cause and effect "laws" of taphonomy have been established through methodological uniformitarianism or actualistic research, yet Lyman contends that they are ahistorical and "do little to *explain* the fossil record…in the sense of helping us understand *why* taphonomic processes occur in the first place or *why* taphonomic processes operate the way and in the temporal order that they do (Lyman 1994:464)."

Similarly, Gifford (1982) attributes this theory deficiency to a general lack of establishing goals of what can be learned with actualistic research, and in establishing how uniformitarianism and actualism can properly direct research. Uniformitarian assumptions have been under criticism within the field of paleoecology. This is partly because the past cannot be observed to empirically determine if the same processes are at work, and partly because it does not allow room for potential past processes that no longer exist, which often leads to the invocation of "ad hoc arguments (Gifford 1982; Lyman 1994:51)." Proponents for the method argue, "(t)he occasional necessity of invoking ad hoc arguments is due largely to incomplete knowledge of present processes, not some internal weakness of the method (Lyman 1994:51)."

Lyman (1994) notes that criticisms of uniformitarianism often stem from confusion between substantive and methodological uniformitarianism, where the former is context-specific. Specifically, when human and animal behaviors or culture are considered as variables that affect the deposition of an organism, a uniformitarian approach can be problematic in providing explanations (Gifford 1982; Lyman 1994). One cannot assume that behaviors and cultural processes have remained the same over time. In addition, causal linkages between an effect and a process are not always substantiated (Gifford 1982; Lyman 1994). Uniform principles are often invoked to establish inferences that may not have much supporting data and can border on speculation (Gifford 1982).

Another component of the problem is the myriad patterns and variables that make up the multivariate nature of taphonomic analyses (Lyman 1994). The multivariate essence of taphonomic data has made it difficult to create models that may be applied to new cases and has also hampered the building of theory (Lyman 1994; Dirkmaat and Adovasio 2002; Nordby 2002), and yet "(v)ariability in the decay rate of the human body is the rule (Mann *et al.* 1990:110)." Factors that alter a carcass are specific to any given environment. They influence and alter one another, which ultimately produces a distinctive effect on the remains (Mann *et al*. 1990; Lyman 1994; Sorg and Haglund 2002). The combined uniqueness of the remains, their context and the natural processes at work create an inimitable ecosystem, with the carcass at the heart of it. What makes the decomposition setting and process so idiosyncratic for each case are not only those intrinsic and extrinsic variables, but also the epidemiological and cultural variation. The epidemiological elements are the driving force for why a set of remains ended up undiscovered within a particular setting and therefore also need to be accounted for. The extrinsic, intrinsic and epidemiological factors encompass a broad array of scientific domains. Consequently, the forensic sciences are necessarily multidisciplinary. Each discipline carries it's own set of theories, assumptions, and explanatory models, to be variably applied, and dependent on the context of the taphonomic setting (Nordby 2002). The many variables and frameworks from within multiple disciplines have in the past made it difficult for forensic taphonomists to move beyond the descriptive case study and towards the creation of quantitative models with the power to make robust generalizations (Ross and Kimmerle 2009).

> Nordby (2002:32) contends that: "(f)orensic taphonomy may at this time exist as a collection of hodge-podge theories, pasted together from many sciences, mixed with archaeological practices, and loosely accumulated to defend case-specific explanations and guide the discovery, and eventual explanation of specific decomposing human (or other) remains."

The constituents that contribute to decomposition are multivariate and the study of these processes is necessarily multidisciplinary by nature (Lyman 1994; Nordby 2002:32). Forensic anthropologists can move past idiosyncratic explanations by utilizing multivariate quantitative models that allow for case-by-case variation, but still hold predictive power.

Present and Future Epistemological Directions

What direction should forensic taphonomists pursue to develop a stronger theoretical foundation? Lyman (1994) and others have suggested ecological theory as a promising gateway towards a more sound theoretical development in modern forensic taphonomic research (refer to Haglund and Sorg 1997a,c, 2002a). The ecological approach is suited to forensic taphonomic endeavors because it enables consideration of the interaction between a body and its surroundings, which facilitates the process of reconstructing a death event. By definition, ecology is concerned with "the interactions that determine the distribution and abundance of organisms (Krebs 1972:4)." With this definition, Krebs (1972) intended to stress the importance of relationships among elements that compose an ecosystem, and that affect species' distributions and abundances.

Whereas the paleoanthropologist or paleoecologist may take a perspective that encompasses an entire ecosystem, forensic taphonomy is exclusively concerned with the environment's interactions with the deceased human body. This narrowed and anthropocentric emphasis on one organism over all others has been rightly noted as arbitrary in focus (Sorg and Haglund 2002), but is well suited to the purpose of inquiry. Therefore, the unit of analysis in forensic taphonomy is the decedent and the ambient micro-ecosystem or the environment of deposition, where environment is defined as any component of the ecosystem that interacts with the carrion in question. From an ecological perspective, this means that forensic anthropologists are focused on the organism level, just below the population level (Krebs 1972). Forensic taphonomists may also be interested in analysis at the community level, which is just below the ecosystem level (Krebs 1972:10), but the community is redefined as any species that have interactions with the carrion.

When considering human decay, the various levels of analysis and complexity within an ecosystem become important because "cadaver decomposition is likely an important ecosystem process (Carter et al. 2007:13)." The death of an organism can be framed in terms of the *biogeochemical cycle,* where in life, the organism takes in nutrients from the environment and in death they are concurrently returned (Lyman 1994). Through the lens of ecology, the body is viewed as a "centerpiece of a newly emerging microenvironment (Sorg and Haglund 2002:5)." The body is broken down through autolysis, putrefaction and anthropophagy and nitrogen and nutrients surge back into the surrounding area, creating a "cadaver decomposition island (Carter et al. 2007:12)." The remains continue to interact with their environment through chemical, biological and physical processes that bring nutrients to the newly emerging ecosystem, and over time the two coalesce (Haglund and Sorg 1997c; Mann *et al.* 1990; Sorg and Haglund 2002). While this process is not unique to human decomposition, the emphasis for anthropologists is solely on human bodies and their surroundings.

Circulatory stasis creates an anaerobic environment that is conducive to expansion of many microorganisms that normally inhabit the gastrointestinal tract or the respiratory system (Carter *et al*. 2007; Clark *et al.* 1997). These nutrients permeate and fertilize the soil, are harnessed by bacteria, plants, insects and scavengers, and ultimately make the immediate environment more heterogeneous (Carter *et al*. 2007). Sorg and Haglund excellently characterize the fluid nature of decomposition, where "the boundaries of the body diverge as decomposing materials penetrate the ground, are carried away by moving water, are digested…or are volatilized to the air or water (2002:5; see also Butera *et al.* 2007)." Ultimately, the cadaver decomposition island makes the surrounding area more fertile and the ecological community more diverse (Carter *et al*. 2007).

Ecological theory provides strong concepts that link the extrinsic environmental setting to the intrinsic changes of the body, but the ways in which these are synthesized needs to follow scientific induction without speculation. To do so, Gifford (1982) essentially makes an argument for practicing sound actualistic science. She suggests that applying uniform assumptions and creating analogues should be "equally conscious and cautious, and that the search for meaning in the archaeological [or forensically significant] record begins with well-conceived and well-executed observations of the contemporary world (1982:525)."

In *General Electric Co. v. Joiner* (1997), the Supreme Court determined that court admissible research must have methods and conclusions that are fundamentally linked, thereby placing emphasis on the importance of rigorous research practices (Christensen and Crowder 2009:1212; Grivas and Komar 2008:772). Gifford's (1982) call for establishing causal links resonates well with the forensic community. Uniformitarianism and actualism are useful postulations for the forensic anthropologist and their utility is enhanced by the relatively recent deposition of forensically significant remains. The issue of time that so burdens the paleoecologist's inferences does not present the same problems to a forensic study. Cases that take forensic precedence were likely subjected to processes during the postmortem interval that still occur during the time of investigation. The medicolegal context necessitates that forensic anthropologists be especially prepared to demonstrate causal links between the facts they analyze and the inferences they derive (Christensen and Crowder 2009; Grivas and Komar 2008). Uniformitarian principles and actualistic research can facilitate the formation of these relationships.

While actualistic research can help establish cause and effect relationships among taphonomic variables, the infinite number of factors that can build on or disguise one another makes it difficult to generate comparable studies (Lyman 1994). Grivas and Komar expressed concern towards quantification of taphonomic changes precisely because there is “infinite variation” associated with the involved processes (2008:773-774). First, more research needs to be done on the potential effects of taphonomic processes “but also the dynamics of the actual events that produce them (Gifford 1982:493).” Specifically, there needs to be more focus on the range of variation that taphonomic processes can produce on a body within specific contexts. If the context is controlled for, the interplay of extrinsic variables can be accounted for in part. Controlling for environmental context can be accomplished by doing more comparisons among forensic cases through retrospective studies.

Researchers must also strive to substantiate a causal linkage between extrinsic forces and their intrinsic effects (Gifford 1982; Gould 1965). Gifford (1982:493) points out that “the search for regular and ecologically relevant linkages between static attributes of the fossil record and their dynamic causes and associations is the key to progress in understanding the prehistoric evidence." To assume uniformity of a process, there should be several lines of evidence that provide a good reason to do so (Gifford 1982). Therefore, actualism is an important methodological stance within forensic anthropology, as it is within many other branches of science.

Utilization of actualistic research can be seen as reflected in the forensic taphonomy literature. The strong need to establish causal links for forensic analysis has led to countless studies on the taphonomic processes that may affect a body after death (refer to Haglund and Sorg 1997, 2002a). To reconcile the many segmented contributions to taphonomic research (i.e., case, retrospective, experimental and environmentally specific studies), scientists must work to collect more data on decomposition that can be compared to the existing literature in a comprehensive manner (Dirkmaat and Adovasio 1997). Additionally, there needs to be a greater reliance on quantitative methods, as they can be used to construct more concrete inferences than qualitative descriptions alone (Kimmerle and Jantz 2008; Ross and Kimmerle 2009). Quantified anthropological methods with known or potential error rates are more likely to satisfy the reliability factor of the *Daubert* standard (Christensen 2004; Christensen and Crowder 2009). Lyman (1994) notes that analyses of covariance within dimensions of taphonomic research will help in making theoretical generalizations. Multivariate statistical methods are needed so that all factors identified as having an important influence on the rate of decay can be accounted for.

Rigorous actualistic investigation in conjunction with multivariate statistical analyses will quantify a model's predictive value and potential error rate as well as produce conclusions that can be tested for reliability within the forensic community, which is critical for admissibility in court (Ross and Kimmerle 2009).

> Kimmerle and Jantz (2008:522) said, "(t)he use of scientific methodology as evidence in criminal courts typically requires that it is accepted by the general scientific community and that probability levels or error estimates are provided when appropriate."

In other words, methods used for determining the circumstances surrounding a death will only withstand scrutiny in a court of law if they have been empirically validated (Christensen 2004; Christensen and Crowder 2009; for examples, refer to Kimmerle and Jantz 2008; Love and Marks 2003). The applicability of anthropological methods to forensic cases therefore depends on the generation and professional publication of new methodological research (Kimmerle and Jantz 2008:522).

More research is also needed on the multivariate processes that lead to undiscovered victim remains and that affect differential decomposition. The incorporation of ecological theory and uniformitarian methodology is a step in the right direction, but this approach only accounts for a portion of taphonomic variation. Ecological theory is applicable to extrinsic natural processes such as wind erosion or climatic cycles and even some intrinsic transformations such as cellular death. Yet, ecological theory cannot account for human behavior or cultural processes that have caused a victim to remain undiscovered and that may have traversed the remains during the postmortem interval.

What sets forensic anthropologists apart from pathologists or traditional taphonomists is their distinct ability to embrace a holistic approach to death investigation. Forensic anthropologists are in a unique position to incorporate all variables and adequately contextualize the taphonomic findings within the whole case surrounding them. An anthropological model that incorporates an epidemiological framework addresses the specific questions asked in a death investigation: what is the time since death, the victim's identity, the cause of death, and the manner of death?

This study aimed to adapt and incorporate Kimmerle and Baraybar's (2008) epidemiological model with the currently employed ecological focus for forensic research on human decomposition. This intricate approach comprehensively encompassed the many biological, cultural, epidemiological and environmental aspects of investigating unaccompanied deaths and their subsequent postmortem intervals. This new model as applied to forensic investigations of solitary deaths will pave the way for research that yields a more holistic understanding of people who die alone. Further, the anthropological model will move this body of research beyond the idiosyncratic case study and towards more robust analyses with meaningful results both to the forensic world as well as the anthropological community.

This research empirically identified the multitude of extrinsic factors that influence decompositional change as well as how they intrinsically transform the remains by critically evaluating the popularly employed model created by William Bass (1997) as it is applied to variable settings in Nebraska. This study revealed demographic information about who it is that dies alone and goes undiscovered for variable amounts of time, which is valuable for identifying behavioral and demographic patterns that are indicative of those whose lives and deaths have become disjointed from society. Through the incorporation of cultural, extrinsic and intrinsic components of solitary deaths, this research created a predictive model for the postmortem interval that may be applied to a variety of enclosed settings, and it is hoped that this model will create a bridge among many seemingly unique scenarios to produce something with predictive and explanatory value.

Intrinsic Transformations

Death may be seen as a process that begins with cessation of the heart (Gill-King 1997). When the heart stops pumping, blood no longer carries oxygen to the body's cells and they become deprived of oxygen (anoxia), which sets in motion an array of processes that create decompositional change (Clark *et al*. 1997; Gill-King 1997). Although timing of these processes is highly dependent on environmental factors, they unfold in a logical order that make them excellent indicators for the estimation of time since death during the early postmortem interval, and serve as a "postmortem clock (Gill-King 1997; Perper 2006:94)." Anthropologists attempt to study these intrinsic changes by constructing stages that a body transcends as it passes from being recently deceased to being completely skeletonized. The processes in which the anthropologist is most concerned are those "physicochemical changes" that are observable and that begin to occur soon after death, such as: ocular alterations, livor mortis, rigor mortis, autolysis and putrefaction (Perper 2006:94).

Livor Mortis

Livor mortis (postmortem hypostasis) is the pooling of the blood in inferior portions of the body as a result of circulatory stasis and gravity (Clark *et al.* 1997; Perper 2006). This phenomenon may be visible as early as fifteen to twenty minutes after death but is more commonly seen after about two hours. As the blood continues to settle, the lividity becomes more conspicuous and eventually turns from red to purple (Clark *et al.* 1997; Perper 2006). The purple discoloration is a result of oxygen no longer binding with hemoglobin on red blood cells, which produces a purple pigment called deoxyhemoglobin (Clark *et al.* 1997).

Initially, the lividity is considered unfixed, meaning that blood is still able to move within the capillaries. When pressure is exerted on livid skin, the blood is pushed out and leaves a whitened area, an occurrence known as blanching. As the body continues to acclimate to the ambient temperature (algor mortis), the blood congeals and diffuses into surrounding tissues, and the dermal fat surrounding the capillaries solidify (Clark *et al.* 1997; Perper 2006). These changes make the lividity "fixed," where blood will not migrate when pressure is exerted on the affected areas. Fixation usually occurs approximately four to six hours (Clark *et al*. 1997), or eight to twelve hours postmortem (Perper 2006).

Autolysis

Living cells are constantly at work to maintain biological order, from the cell to the organismal level (Alberts *et al*. 1998). This normal human biology can only function within fairly narrow limits of temperature and pH (Clark *et al*. 1997; Gill-King 1997). Integral to cellular activity is the process of central metabolism, where cells procure energy from carbohydrates and other environmental compounds and use it to drive normal cellular processes, such as cell products, maintenance, and division (biosynthesis; Alberts *et al.* 1998; Gill-King 1997). Within each cell, energy is stored in the form of adenosine triphosphate (ATP) to be used when needed. Hydrolytic enzymes (hydrolases) normally function to break down carbohydrates and proteins for ATP energy production (Clark *et al*. 1997). Hydrolases are contained within "membranous sacs" called lysosomes, which are responsible for "intracellular digestion" and work best within acidic environments (Alberts *et al.* 1998:476).

Once the heart stops pumping, the organism's cells are denied oxygen and they can no longer maintain biosynthesis (Gill-King 1997). As a last-ditch effort of survival, the cells switch from central (oxidized) metabolism to a fermentative (anaerobic) metabolic pathway, which produces abundant quantities of lactic acid and consequently lowers the cells' pH (Gill-King 1997). The anaerobic, fermentative pathway does create some ATP energy, but ultimately it is not enough to sustain cellular processes and they enter into cell death (Gill-King 1997).

The breakdown of body tissues caused by digestive enzymes is known as autolysis (Clark *et al*. 1997; Gill-King 1997; Perper 2006). The body's cells are no longer able to engage in maintenance activities (biosynthesis) and the membranes of lysosomes begin to deteriorate (Clark *et al.* 1997; Gill-King 1997). The digestive enzymes are released from membrane-bound organelles into the cytoplasm, where they destroy the cellular membrane (lysis) and are liberated into the body (Clark *et al*. 1997; Gill-King 1997). The dissolution of cell membranes causes the cells to separate from one another, which at the macroscopic level is known as "tissue necrosis (Gill-King 1997:96)."

The rate at which catalytic enzymes metabolize is dependent on temperature, where an increase in heat will increase their work speed, until they reach a temperature that causes denaturation (60˚C, 140˚F; Clark *et al.* 1997; Gill-King 1997). Therefore, "autolysis will be accelerated by antemortem fever, exertion, or a high ambient temperature (Clark *et al*. 1997:153)." Autolysis commences approximately four minutes after death (Vass 2001). However, the time that autolysis begins varies among cell, tissue and organ types (Clark *et al*. 1997). Autolysis first starts in cells that are highly metabolically active, and hence possess more lysosomes and hydrolytic enzymes for the production of ATP energy, biosynthesis or membrane transport (Clark *et al.* 1997; Gill-King 1997).

As a result of variable timing in the onset of autolysis among cell types, there is a common order of the intrinsic process of tissue decomposition and these changes may be grossly seen approximately forty-eight hours postmortem (Clark *et al*. 1997; Gill-King 1997). Internal organs that are affected by autolysis take on a "doughy consistency (Clark *et al.* 1997:154)." The first organs to undergo decompositional change are the: intestines, stomach, pancreas, liver, heart, blood and circulation, due to their high quantities of hydrolytic enzymes (Gill-King 1997:97). Secondly, the lungs and air passages degrade, followed by the kidneys and bladder. The brain and related nervous tissues are highly engaged in metabolism and tend to decompose rather quickly. The brain's high concentration of hydrolytic enzymes cause cell lysis, which results in liquefaction ("liquefactive necrosis"; Gill-King 1997:97). The skeletal muscles are often the next tissue group to decompose. The hydrolytic enzymes of muscle tissue tend to denature, which results in "coagulative necrosis (Gill-King 1997:97)." Integument and connective tissues are composed of collagen, a durable organic material, and hence these tissues often survive the longest (Gill-King 1997:98).

As the cells degrade, carbon dioxide is released and accumulates in the blood, which makes the pH decline at the tissue level so that the body becomes more acidic (Clark *et al.* 1997; Gill-King 1997). The blood's lowered pH triggers coagulation that results in postmortem blood clotting within the body's arteries and veins (Clark *et al.* 1997). As the blood's pH continues to decline, the clots eventually reliquify. This process tends to begin and end at approximately the same time as rigor mortis (described below), although they are independent of one another.

The termination of circulation deprives red blood cells of oxygen, and hemoglobin and oxygen are no longer able to bind, which creates deoxyhemoglobin and makes the blood purple (Clark *et al*. 1997). Hemolysis (bursting of red blood cells) occurs within blood vessels and they become discolored. This staining is apparent in the superficial veins and arteries, which trace bluish lines across the body's skin, an artifact known as marbling.

Skin slippage is an intrinsic phenomenon caused by cell lysis near the interface of the dermis and epidermis (Clark *et al*. 1997). The release of hydrolytic enzymes causes the dermis to separate from the epidermis so that the latter peels and can be wiped off in a thin layer. Fluids produced as a byproduct of autolysis sometimes accumulate between the separated tissues and form what are known as postmortem bullae, or fluid-filled bubbles that form between the epidermis and the dermis (Clark *et al*. 1997). The loosening of the epidermis also frees nails and hair from their respective origins, and they are likely to loosen or fall out.

Rigor Mortis

Rigor mortis is the stiffening of all the muscles in the body as a result of chemical changes produced by autolytic processes (Clark *et al*. 1997; Gill-King 1997). The sarcoplasmic reticulum is a specialized type of endoplasmic reticulum organelle within muscle cells that contain large stores of calcium (Junqueira and Carneiro 2005). Sarcomeres are structures within the myofibrils of muscle cells that are joined longitudinally and span the length of a muscle (Gill-King 1997; Junqueira and Carneiro 2005). Sarcomeres contain actin and myosin, the proteins responsible for muscle cell contraction. In a living body, the sarcoplasmic reticulum releases calcium into the sarcomeres (Gill-King 1997; Junqueira and Carneiro 2005). Calcium frees the binding sites on the actin filaments, and actin and myosin bind via "locking chemical bridges (Gill-King 1997; Perper 2006:102)." These bridges slide the actin across the myosin filament within each sarcomere and produce a muscle contraction (Gill-King 1997; Junqueira and Carneiro 2005). ATP energy is used to pump the calcium back into the sarcoplasmic reticulum, which separates the actin-myosin bond and causes the muscle to relax (Gill-King 1997).

In a deceased human, autolytic release of enzymes destroys the membrane of the sarcoplasmic reticulum and releases calcium into the sarcomere (Gill-King 1997). The same process that produces muscle contraction occurs by default in the autolytic postmortem phase. However, there is no ATP energy to pump the calcium back into the sarcoplasmic reticulum, and hence the contraction persists as rigor mortis (Gill-King 1997). Rigor is ultimately ended by the autolytic release of digestive enzymes within muscle cells (cathepsins). Once released, these enzymes separate the actin from the sarcomere, which allows the muscles to break rigor and relax (Gill-King 1997).

Perper (2006:101) states, "Rigor mortis develops and disappears at a similar rate in all muscles." Therefore, smaller muscles will become rigid and lose rigidity sooner than larger muscles, and for this reason it is often first seen in the facial and the masseter muscles (Clark *et al*. 1997; Perper 2006). There is some variability in reports of when rigor typically develops and disappears. Perper divulges that rigor may begin as early as a half hour to an hour after death, "increases progressively to a maximum within twelve hours, remains for about ten or twelve hours and then progressively disappears within the following twelve hours (2006:101)." Clark *et al*. (1997) report that rigor begins within two to three hours postmortem, is fully set after twenty-four hours, and dissolves by forty-eight hours. Gill-King (1997) reports a somewhat later time frame; rigor develops within four to six hours and disappears within twenty-four to forty-eight hours. Comprehensively, these reports suggest that rigor may develop within one to six hours postmortem, become fully set within twelve to twenty-four hours, and disappears within twenty-four to forty-eight hours.

Muscle mass, temperature and metabolic status are important variables that affect the length of time needed to develop and dissolve rigor mortis (Clark *et al*. 1997; Gill-King 1997; Perper 2006). High external temperatures, metabolism, fever, and low muscle mass are associated with increased rates of rigor mortis. If the ambient temperature is very warm, rigor might begin and end within nine to twelve hours (Perper 2006:102). Characteristics intrinsic to the individual will influence the timing of rigor. Bodies with more muscle mass will tend to have more glycogen to be converted to lactic acid via fermentative pathways, and the lactic acid will lower the muscle's pH and accelerate the process of membrane deterioration (Gill-King 1997). Due to infants' and the elderly's low muscle mass, they may not fully develop rigor or it may develop and resolve quickly (Gill-King 1997; Perper 2006). In addition, large body surface area will enable the body to cool more quickly, and slow the rate of rigor.

Putrefaction

Putrefaction is the intrinsic dissolution of the body caused by extrinsic bacteria and other microorganisms normally residing in the body (Perper 2006). This process may be accelerated by heat, sepsis, diabetes, fever or a large amount of adipose tissue (Perper 2006). Sepsis introduces more microorganisms than what would be found in a healthy body. The accelerated rate of putrefaction in persons with diabetes appears to be related to their higher levels of sugar, which may serve as a source of nutrients for anaerobes (Perper 2006).

When cells are no longer receiving oxygen from red blood cells, they switch to fermentative metabolic pathways, which creates an anaerobic atmosphere that is conducive to the proliferation of bacteria in the large intestine (Gill-King 1997). Somewhere between 96 and 99% of colonic bacteria are anaerobic. Following the autolytic release of carbohydrates, protein and lipids, bacteria begin to break these organic structures down, which creates macroscopic putrefactive changes (Clark *et al.* 1997; Gill-King 1997). The bacteria engage in "bacterial carbohydrate fermentation" and expel various gases and organic acids that largely contribute to the decline in the body's pH after death (Gill-King 1997:99).

Clark *et al.* (1997:155) state: "The rapid production and accumulation of gases causes both physical and chemical changes in the decomposing body which are superimposed on the autolytic processes described above." The gases produced accumulate within the bowel as well as between tissue layers via the circulatory system, and produce a postmortem artifact called bloating (Gill-King 1997). Bloating can first be seen in the face and causes the lips to protrude, followed by the large swelling of the abdomen (Clark *et al.* 1997). In men, the scrotum also swells.

Before rigor sets in, the muscles of the body relax and the body will often soil or urinate as a result of loss of muscle tone (Perper 2006). Segmented portions of the digestive tract often get passively transferred, and when the duodenum passes on bile to the stomach, bile will assist in autodigestion of the stomach wall and contents (Perper

2006). The gastrointestinal tract and the contents of the stomach undergo decomposition from both autolytic and putrefactive processes and create an artifact known as purge fluid (Clark *et al*. 2006). Putrefactive gases force purge fluid out of the body through the nose and mouth.

In a living body, the spleen digests dilapidated red blood cells and this digestion enables the liver to produce multi colored pigments. After death, autolytic lysing of pancreatic cells releases bile and multiple colors of pigments into the circulatory and abdominal tissues (Gill-King 1997). The anterior portion of the abdomen eventually develops a green discoloration as a result. In addition, the degeneration of hemoglobin throughout the body also "produces widespread pigment coloration effects in the body's tissues (Gill-Clark 1997:101)."

Extrinsic intestinal bacteria normally break down proteins through a process known as decarboxylation, which produces a number of products, including hydrogen sulfide gas, putrescine and cadaverine, the latter two of which are responsible for decompositional odors (Gill-King 1997). Hydrogen sulfide breaks down amino acids that contain sulfur when amino acids are in the presence of red blood cells that are in the process of lysing. Sulfur binds with hemoglobin to produce "greenish-purple" sulfhemoglobin molecules (Gill-King 1997:101). The process obviously occurs where there are red blood cells and consequently the superficial vessels and the areas affected by livor mortis will turn from green to purple to black (Clark *et al*. 1997; Gill-King 1997). Therefore, this process is also responsible for the macroscopic color changes associated with livor mortis and the superficial veins and arteries, a phenomenon known as marbling. The process of sulfur binding to hemoglobin is also affected by the ambient temperature (extrinsic) and by the percentage of subcutaneous fat (intrinsic) on the body (Gill-King 1997).

Mummification and Adipocere

Mummification is an intrinsic taphonomic change associated with dry climatic conditions during the depositional time frame (Mann *et al.* 1990). Perper describes, "Mummification results from drying of tissues under conditions of high environmental temperature, low humidity and good ventilation (2006:114)." These conditions cause the skin or other soft tissue to dehydrate and tighten as body fluids evaporate into the surrounding air (Clark *et al*. 1997:157; Perper 2006:115). The rapid desiccation and shrinkage of the tissues sometimes cause them to tear in the "groins, neck and armpits (Perper 2006:115)." Mummification of the skin typically first occurs in the knees, elbows, fingertips, and toes, where it takes on the appearance of "shriveled, with wrinkled, firm, brown skin (Perper 2006:115)." Perper describes, "(o)nce mummification is fully developed, the body remains preserved as a shell for long periods of time, even years (2006:115).

Mellen and colleagues have described adipocere as "a waxy or greasy decomposition product formed from hydrolysis and hydrogenation of adipose tissues (1993:91)." This foul-smelling intrinsic development first appears grey, with a "soft, greasy, clay-like, plastic consistency (Perper 2006:115)." Haglund notes that over time it can become "hard and brittle" and then remain for years (Haglund 1993:812; Mellen et al. 1993). Like mummification, adipocere formation protects the integrity of the soft tissue remains and slows the rate of taphonomic change (Perper 2006). This taphonomic feature tends to affect the "subcutaneous tissues of face, extremities, buttocks and female breasts (Perper 2006:115)." On account of adipocere's known ability to decrease the rate of decay and that temperate affects its onset, adipocere formation may be an adequate intrinsic factor to use in prediction of the postmortem interval or especially, for the prediction of accumulated degree days.

Taphonomic Influences

To deconstruct the complexity of decay, it is necessary to understand the myriad of factors that interface in the decomposition process and affect the rate of taphonomic change. These factors make decomposition a process that is mostly dependent on extrinsic environmental conditions and the intrinsic metabolic status of the individual prior to death (Perper 2006).

Factors that influence the rate of decomposition are primarily those extrinsic and cultural considerations that interact with or regulate access to the remains. Extrinsic physical factors that may accelerate the decomposition process would include sunlight, wind exposure and the presence or absence of groundwater and soil acids (Ubelaker 1997). Environmental factors are connected in their influence as they alter one another so that the effects of one element cannot be isolated (Mann *et al*. 1990). Mann and coworkers (1990:104) note, "(t)o isolate one variable would, in reality, give us only a tiny piece of a biased puzzle." There has been an extensive amount of research on identifying, understanding, and determining the contribution of individual factors, although most of this research is particular to outdoor scenarios (i.e., Mann *et al*. 1990; Rodriguez and Bass 1983). Conclusively, temperature has been identified as the most important variable in the rate of decay (Mann *et al.* 1990).

Temperature

Mann and colleagues (1990) found that ambient temperature has the greatest control over the rate of decomposition. Heat accelerates the process of autolysis by increasing the speed of catalytic enzymes within the body and consequently the increased rate of autolytic cell breakdown increases the rate of putrefaction (described below; Clark *et al*. 1997; Gill-King 1997; Perper 2006). Temperature also influences many other variables that act on decomposing remains. For example, plants, animals and insects are more active and exist in larger numbers during periods of warmer temperatures, and thus decomposition proceeds at an accelerated rate in warm climates. In contrast, cold temperatures tend to preserve soft tissue and prevent insects from thriving (Mann *et al*. 1990). These relationships reveal temperature as a driving force in the rate of decomposition.

Perper (2006:108) provides an example from a couple that were killed within minutes of one another but decomposed at substantially different rates. The woman was murdered in the basement where the temperature was cool whereas the man was killed in the upstairs portion of the house. The outside temperature had been a warm 90° F and so the man's body had been subjected to substantially warmer temperatures during the couple's forty-eight hour postmortem interval. The woman's body may have been classified as fresh with very little decompositional change, yet the man's body had rapidly decomposed and was showing evidence of skin slippage, bloating and green discoloration at the time of discovery. This case study exemplifies the powerful influence of temperature on the rate of human decay.

Accumulated Degree Days

Accumulated degree days (ADD) are a measure of temperature over time that has traditionally been used to determine the rates of insect development (refer to Higley and Haskell 2001; Haskell 2006) but can be dually applied to estimating the rate of human decompositional change. ADD are useful for estimating the age of insects because insects cannot maintain their own body temperature, and so insect development is largely dependent on ambient temperature (Higley and Haskell 2001:288). ADD models are species specific and are based on linear regression models that consider the maximum and minimum temperatures of which a specific species can develop (Higley and Haskell 2001). Accumulated degree days (ADD) are calculated as the "minimum developmental threshold" temperature multiplied by time (Higley and Haskell 2001:290). Insects' minimum developmental thresholds are commonly regarded as 6˚C and 10˚C (Higley and Haskell 2001:290).

To apply this method towards the estimation of time since death, the PMI must be quantified in degree days (DD). In entomological research, the species of insect found on the remains is identified and local weather data are acquired from a weather station

(Haskell 2006). To determine the ADD, each day of the PMI where temperatures met the minimum developmental threshold are totaled. The accumulated minimum developmental threshold temperatures over the PMI are then compared to the known ADD that are necessary for the insect species to reach the stage of development in which they are found (Haskell 2006; Higley and Haskell 2001). The estimated PMI will equal the number of days needed to accumulate the minimum developmental temperature specified by the DD regression model (Higley and Haskell 2001).

Accumulated degree days can also be used to measure temperature over time for estimation of the rate of decay. In a study by Megyesi and colleagues (2005), the quantification of ADD was modified from the traditional approach so that only temperatures above 0˚C were summed for each day that composed the postmortem interval. Megyesi *et al*. cited Vass *et al.* (2001) research, stating, "because of salt concentrations in the human body, decomposition will occur down to 0˚C (2005:621-622)." They argued that the minimum temperature needed to contribute to the ADD could be lowered to 0˚ C. This study therefore disregarded temperatures associated with insect development and modified the definition of ADD to be the summed mean temperatures that were above 0˚ C for all days that composed the postmortem interval. The Megyesi *et al*. (2005) approach to calculating ADD was adopted within this study.

Prediction of ADD rather than PMI days for time since death estimations is a relatively novel development, but has been implemented by other researchers (Megyesi *et al.* 2005; Vass *et al*. 1992; Love and Marks 2001). In a survey of forensic anthropologists' case studies from across the United States, Mary Manhein (1997) found that most anthropologists identified climate as one of the most important variables affecting the rate of decay. Additionally, in her discussion Manhein notes:

> "Respondents' comments indicated that more specific information in regard to recording such variables as climate was needed. To overcome such a problem, climatic conditions specific to each case's microenvironment need to be recorded in such a way as to be universally tabulated (Manhein 1997:478)."

The primary benefit that comes from using ADDs rather than actual days is that it compounds time with temperature, the most important dictator in the rate of decay. The other benefit that comes from using accumulated degree days is the standardization of rates of change, which allows the same system for estimation of the PMI to be used globally.

Cause and Manner of Death

With unexpected deaths, investigators reconstruct circumstances surrounding death to establish the cause and manner of death. Adams and colleagues (2006:439-440) define the cause of death as "the original underlying medical condition which *initiates* the lethal chain of events culminating in death." Establishing cause of death can be difficult as there can be multiple causes that vary in their levels of contribution towards cessation of life. In some instances a medical examiner may need to distinguish between a proximate cause of death (such as a sustained head injury) and the immediate cause of death (such as the bronchopneumonia that the person developed after becoming bed ridden from the injury; Adams *et al*. 2006:440). In autopsy reports and death certificates, cause of death is divided into primary and secondary causes and allows room for causes within each category (Perper 2006:90). Primary causes of death are the immediate causes, such as a gunshot wound to the head, whereas secondary causes are contributory factors such as arteriosclerotic cardiovascular disease. Determining the cause of death can also be important for evaluating the rate of decomposition. Injuries can magnify insects' access to soft tissues and contribute towards rapid soft tissue destruction (Galloway 1997; Galloway *et al*. 1989). Additionally, people who die with sepsis may experience rapid onset of putrefaction due to the increased prevalence of microorganisms within the body (Perper 2006).

The manner of death is "the legal classification of death (Perper 2006:90)." This category speaks to the issue of accountability for a person's demise and has strong legal ramifications (Adams *et al*. 2006). People who die from natural deaths die solely from disease; this category encompasses both infectious and chronic diseases including chronic alcoholism. Accidental deaths are those deaths that were not natural and where there were no harmful intentions involved. Accidental deaths are often traumatic in nature but do not necessitate trauma, such as when a person dies from positional asphyxia or an accidental overdose. A suicidal death does not necessarily have to be violent in nature but occurs when a person intentionally terminates his or her own life. Lastly, homicides are those deaths that occur when a person deliberately kills another person. Within the latter two categories, it is especially important to demonstrate intent because of the legal and social implications associated with suicides and homicides (Adams *et al.* 2006).

Lastly, a death may be classified as undetermined if there is insufficient evidence to provide a legal classification for a death.

Manners of death are epidemiological in nature, as human activities are almost always the acute or chronic agents behind the death event. For example, Daniel Spitz attributes the occurrence of drowning to environmental factors and human factors, the latter of which he describes as "a victim's mental health, medical conditions, drug or alcohol use and swimming ability (2006:847)." These "human factors" may be understood as the epidemiological contributions to a drowning death event. While in a retrospective study it may not be possible to ascertain all epidemiological factors that precipitated a person's death, consideration of the cause and manner of death represent an available source of data that provide an avenue to account for some epidemiological factors. These factors in congruence with other epidemiological variables were explored to provide meaningful information on how human behaviors contribute towards the demographic profile for undiscovered deaths and their associated depositional contexts.

Epidemiological Factors

For the purpose of constructing a forensic taphonomy model, epidemiological factors are defined as any element of human influence that interact with a set of remains or have contributed to the death or deposition of the body in question. Roksandic asserts,

> "both natural and cultural agents should be regarded as taphonomic… External factors such as the time elapsed between death and burial, the treatment of the body prior to burial, and the burial environment…are all primarily cultural (Roksandic 2002: 100, 101)."

Cultural and behavioral factors affect how a person dies, how and where the body is deposited, and what aspects of the outside environment have access to the remains.

A person's identity may also play a role in the peri- and postmortem circumstances. Kimmerle and colleagues note that collective identity places an "individual into a particular cultural, demographic, religious, or ethnic group (2009:180)," which can be estimated through indicators such as age, ethnicity and sex. Contextual identity takes into consideration collective identity as well as behavioral patterns associated with the individual, such as being transient or sedentary (Kimmerle *et al.* 2009). The authors found patterns among collective and contextual identity, location of the crime, and whether or not the case was solved. For this thesis, collective and contextual identities were explored for relationships with taphonomic contexts, manners of death and extended postmortem intervals.

Morten and Lord's (2002) study of child abduction and murder provides an excellent example of how behavior affects taphonomic circumstances. They found that children's "remains were disposed of in different scenarios depending upon the motivation of the offender and the age of the victim (2002:153)." For instance, murderers of neonates, infants and toddlers often did so for "emotional reasons" and the offenders typically deposited the victim's body within or near the home. In contrast, children of 12 to 14 years of age were often abducted and murdered for sexual purposes, and were disposed of five miles or more from the home. Due to the nature of the death event, the offenders usually concealed the bodies where they were deposited (Morten and

Lord 2002). This study encapsulates how behaviors surrounding the death event dictate the taphonomic patterns that ensue.

A case study described by Steadman and Worne (2007) provide another example of how culture and behavior intersect with the taphonomic context. In their case study on canine scavenging within a home, the decedent was an elderly woman who lived alone and rarely interacted with her neighbors. No one came to check on her for four weeks and when it was discovered that she had died, very little of her body remained. Steadman and Worne noted, "(t)he social parameters of this case fit a trend…in which victims of postmortem feeding live alone with one or more pets and are socially isolated (2007:81)." With this passage, the authors are demonstrating the link between the behaviors of the decedent in life to the taphonomic circumstances of her death. This case study illustrates how circumstances surrounding unaccompanied deaths are epidemiological in nature in that cultural and behavioral factors from before death dictate the taphonomic conditions after death. Therefore, the investigation of decedents' taphonomic profiles should include consideration of epidemiological trends.

Burial Factors

For the purpose of this investigation, epidemiological factors under consideration are primarily those directly associated with the remains. For example, the presence of clothing is a factor of human influence that has been associated with a decreased rate of decay, because clothing tends to act as a barrier between the body and the external environment (Galloway 1997; Galloway *et al*. 1989; Komar 1998; Mann *et al*. 1990).

For water burials, it has been found that clothing in conjunction with warm temperatures may also promote the formation of adipocere (Mellen *et al*. 1993). Clothing on remains located in moving water can also facilitate the sloughing of soft tissues from the body (Haglund 1993). Shoes on the deceased serve to protect feet and severely retard the decomposition process (Roksandic 2002:102). Additionally, synthetic clothing and containers have been implicated in severely retarding the rate of decay. Manhein (1997) has found a relationship between the presence of a container around a body and the formation of adipocere. These examples provide support for consideration of human introduced barriers to the body as important in estimation of the rate of decay and the postmortem interval.

For bodies within structures such as vehicles or hotel rooms, the structure itself can serve as a human influenced barrier between the body and the extrinsic constituents of the outside environment, such as insects (Haskell 2006). The degree of separation between the corpse and the outside setting depends on how well sealed the structure is, such as whether or not there are open windows. Enclosed decomposition settings also present other burial factors of human influence, such as the surface of deposition and the potential for climate control. Therefore, factors such as the surface of deposition, whether or not the body is buried, indoors or wrapped are all important epidemiological considerations that affect insects' access to the remains and must be considered for estimation of the postmortem interval (Mann *et al.* 1990).

To assess the human influences of the enclosed environment, this study examined: clothing and other barriers to the body, whether heat or air conditioning were used, windows were open or closed, the surface of deposition, and the cause and manner of death. These epidemiological parameters are capable of being observed in a retrospective study and were used to improve the estimation of the postmortem interval for enclosed settings.

Location

Due to the numerous physical and biological variables affecting the sequence and length of postmortem changes, it is logical to assume and has been empirically demonstrated that location of deposition will affect the rate of decomposition (Galloway 1997; Galloway *et al.* 1989; Komar 1997; Mann *et al.* 1991; Voss *et al*. 2008). A review of the literature indicates that there are many unique and specific factors that culminate to produce highly variable postmortem intervals (PMI), which are environmentally and geographically specific (Mann *et al*. 1990). The depositional context will largely determine which variables affect a carcass and the degree of influence for each, which affects how decompositional change correlates with PMI (Galloway 1997; Galloway *et al*. 1989; Komar 1998; Mann *et al.* 1990; Rodriguez and Bass 1985; Roksandic 2002). Researchers can control for some variability and intersection of extrinsic forces by analyzing differential contexts separately and by taking a multivariate approach to analysis. For this thesis, environmental variation was considered and all settings represented were examined separately.

Outdoor Surface Locations

Previous research has yielded data on the characteristics of decay at various stages, which have become exemplary standards for the study of the postmortem interval among variable climates for surface depositions (Bass 1997; Galloway 1997; Galloway *et al.* 1989; Komar 1998; Rodriguez and Bass 1983). A review of these analyses reveals general properties that may be identified on a decomposing body, identifies important extrinsic factors that regulate the rate of decay, demonstrates regional variability, and ultimately allows for a more critical comparison among the observations from Nebraska and previous research.

For outdoor surface locations, insects are largely responsible for soft tissue removal (Bass 1997; Mann *et al*. 1990). Entomological information is useful because "decay rates of human cadavers have a direct relationship to the successional pattern of carrion frequenting insects (Rodriguez and Bass 1983:423)." The contribution of scavenging is almost entirely dependent on necrophagous organisms' access to the remains. Conversely, barriers between the body and the external environment will tend to impede insects' access and decelerate the process of putrescence (Bass 1997; Galloway 1997; Galloway *et al*. 1989; Mann *et al*. 1990; Rodriguez and Bass 1983). For example, heavy rains may hamper flies' ability to lay eggs on a carcass; yet if a maggot mass has already formed, rain is not likely to affect them (Mann *et al*. 1990).

The most precise method for estimating the postmortem interval utilizes the development and life cycles of fly species and the succession of insect species that colonize rotting remains (Haskell 2006). The colonization sequence is primarily composed of flies (order Diptera) and later, beetles (order Coleoptera), who seek out necrotic tissue and lay their eggs in the natural openings of a carcass, such as the mouth and nose (Bass 1997; Rodriguez and Bass 1983).

The ideal circumstances for maggot proliferation involve moist, warm and dark conditions (Bass 1997). When maggots colonize a body that is exposed to the sun, they will create a dark environment by consuming only the skin that is in contact or near to the ground, while leaving the rest as a shield. Consuming the skin near the ground also provides an aperture to allow air to pass into the carcass where the insects inhabit (Bass 1997).

For outdoor scenarios, flies have been found to land on the remains within a few hours and have eggs hatching within six to forty hours (Rodriguez and Bass 1983). After the larvae have reached their full size, they relocate from the body to surrounding soil or other covering and pupate for six to eighteen days. While flies prefer warm temperatures, blow flies (family Calliphoridae) are able to live and reproduce when temperatures exceed negative fifteen degrees Celsius (Bass 1997; Rodriguez and Bass 1983). The timing of insect development is dependent on temperature. Thus, the contributions of insects and temperature towards the rate of decomposition are often intertwined.

In an experimental study, Rodriguez and Bass (1983) used the physical characteristics of the remains to identify four basic stages of human decomposition, and found that each stage was strongly associated with certain families of insects. Bass (1997) created a timetable for outdoor surface remains found during the summer months in warm, moist climates, in which he attributed most of the soft tissue loss to the work of insects (Table 2.2; also see Appendix A). Bass' (1997) stages appear to be a further development of the previous analysis by Rodriguez and Bass (1983), and are based on observations from research performed at the Anthropological Research Facility (ARF) at the University of Tennessee (Bass 1997). At the ARF, the remains are fenced in so as to restrict large animals from access to the bodies. Hence, his data do not account for any contributions from large scavengers. The more decomposed the remains are, the larger is the time range in which different bodies achieve that stage. In other words, the time range assigned for the postmortem interval becomes less precise for bodies that decompose for longer periods of time.

Rodriguez and Bass (1983) found that predominant insect species involved in colonizing carrion roughly correlate with the specific stage of decay. The "fresh stage" is primarily associated with flies (Dipteras). According to Bass' (1997) stages, during the "fresh" phase (one day), flies are attracted to the body and begin to lay eggs in its natural openings or in open wounds (Table 2.2). As a result, "egg masses" may appear in these orifices (Bass 1997:183). The cadaver exhibits fluids seeping from the nose or mouth and the veins turn a blue or green hue as a result of putrefaction.

The second phase is that of "fresh to bloated" (first week), where body fluids seep from the mouth, nose and rectum, and the abdomen becomes distended from putrefactive gasses that well up inside the intestines. The "bloated stage" has a continued strong presence of Dipteras and is also accompanied by carrion beetles and clown beetles (Rodriguez and Bass 1983). As a consequence of increased maggot activity, the face becomes rapidly skeletonized (Bass 1997). Molds may appear and beetles grow interested in the corpse. Decompositional odors and discoloration of the veins become more prominent and skin slippage begins to occur (Bass 1997).

The third transition is from “bloated to decay” (the first month), where the intestinal gases have found release and the abdominal region is depressed (Bass 1997:184). The “decay stage” is characterized by the rapid loss of soft tissue, the presence of sap beetles, and the eventual decline in other insects towards the end of this phase (Rodriguez and Bass 1983). Maggot activity subsides and beetles begin to dominate the carcass (Bass 1997). The carcass and the surrounding area may be blackened as a result of contact with the volatile fatty acids that leach from the remains. Much of the soft tissue has decayed away, and the skin may remain intact but mummified, which serves as a barrier to sunlight. Lastly, molds, and if in a moist environment, adipocere may form on the remains (Bass 1997).

During the “dry stage,” sap beetles are joined by dermestid, lemellicorn and checkered beetles (Rodriguez and Bass 1983). The dry stage (the first year) occurs after the first month and involves taphonomic alterations to bone, such as bleaching or moss growing onto the bone (Bass 1997:184). Rodents and wasps may be seen using the remains to build nests. The strong connection between decompositional state of the remains and insect colonization demonstrates that temperature and insect involvement are important factors in the rate of decay for outdoor surface remains.

Table 2.2—Decay Rates Defined by Bass (1997).

Stage	Characteristics
First Day (Fresh)	• Egg Masses will be white and may look like fine sawdust. • Veins under the skin may be turning blue or dark green. • Some body fluids may be seen around the nose and mouth.
First Week (Fresh to Bloated)	• Maggots have hatched and are active in the face. • Lips may be distended because of the maggot mass under the skin. • Skin around the eyes and nose is eaten away exposing bone. • Beatles appear as a part of the sequence of carrion insect activity. • Skin slippage on the body is beginning. • Hair is beginning to slip from the scalp. • Veins are prominent under the skin and are dark blue or dark green. • The odor of decay is present. • Body fluids may be flowing from the nose, mouth, and rectum. • Abdominal areas may be bloated. • Molds of various colors begin to appear on the body. • Mammalian carnivores may be active and will greatly speed up the decrease of soft tissue by eating the decaying tissue as well as bone. • Body fluids (volatile fatty acids) may have killed the vegetation immediately around the body.
First Month (Bloated to Decay)	• Maggot activity is much less and beetles are present on and around the decaying body. • Bloating is past and the body is in the decay phase. • If in the spring, birds may be using hair that has slipped from the scalp to build nests (Mann et al. 1990). • If the body has been covered most of the bones will be exposed where the soft tissue has decayed away. • If the body was not covered, the skin between the skeleton and the sunlight will be intact to protect the maggots around the sun. It will now be getting dry and leathery. If the body lies on its back the dry skin will be holding the ribs together. • Mammalian carnivores may be carrying off limbs and even the skull. • Molds (of various colors) have spread over the soft tissue and on the bones. The area around the body may be stained dark and the body may appear to have been burned. This is from the volatile fatty acids that have leached out of the body during the decay process. • If the body decayed on an incline, these volatile fatty acids will kill the vegetation as it flows from the body. • Adipocere may appear on a body decaying the moist environment. If in the water, the adipocere will first be seen in the area from about 2 inches above to about 2 inches below the water line.
First Year (Dry)	• Bleaching of the skeleton has occurred from the sunlight. • The portions of the skeleton in the shade may have moss or green algae growing on them. • Rodent gnawing may be present along the crest or edges of bones (the eye orbits in the skull, the linea aspera of the femur, etc.). • Mice may be using the skull as a nest. • Wasps may build a nest in the skull if the skull was dry by late March or early April during the nest building period.

* Reproduced exactly from Bass (1997:183-184)

Galloway and colleagues (1989) studied decomposition for outdoor surface depositions in Arizona. The authors found that there was comparable variation in the rates of decay for human bodies that decompose in hot, arid environments. They took into account factors that may affect the rate of decay as well as the presence or absence of physical indicators of decomposition (i.e., marbling), which is similar to what has been done in the current study. Dry conditions often lead to natural mummification where the tissues desiccate and preserve (Mann *et al*. 1990). However, humidity and temperature are entangled processes because seasonal increases in temperature are often associated with seasonal increases in precipitation. Consequently, these variables must often be evaluated simultaneously (Galloway 1997). In conjunction with temperature and humidity, whether the body is primarily exposed to sunlight or shade affects the decomposition process (Perper 2006). Sunshine coupled with aridity leaches the moisture out of a body and causes it to mummify, whereas shady conditions facilitate the retention of moisture (Galloway 1997; Galloway *et al.* 1989). Under extremely arid and sunny conditions, mummification of the skin has also been discerned as impeding the infestation of maggots and hence decelerating the process of soft tissue removal (Galloway *et al.* 1989; Schroeder *et al.* 2002).

Galloway *et al*. (1989) used decomposition phases that approximated those of Rodriguez and Bass (1983), but they also added supplementary subcategories that further described the condition of the remains (Galloway *et al*. 1989; Table 2.3). Rather than suggest a chronological sequence, these secondary categories describe multiple decompositional states within each stage, which makes them widely applicable to a variety of postdepositional contexts. Unlike Bass' (1997) description of transformative changes and his strong focus on insect activity, Galloway *et al*. (1989; Galloway 1997) emphasized the physical state of the remains, which may possess more utility for a less experienced observer when attempting to accurately assign a phase.

For example, a body is considered "fresh" when there are no maggots on the remains and the only obvious postmortem change is lividity (Galloway *et al.* 1989:608). "Early decomposition" begins when the body becomes discolored and is followed by bloating (Table 2.3). "Advanced decomposition" encompasses both moist and dry post-bloat changes, such as considerable maggot activity and drooping of soft tissue for the former, and mummification and desiccation for the latter (Galloway *et al*. 1989:608). A corpse may be considered "skeletonized" when more than half of the bone is exposed, and "decomposition of the skeletal elements" comprises bone breakdown, such as "bleaching, exfoliation, and cortical breakdown (Galloway *et al.* 1989:608)."

Table 2.3—Stages of Decay Defined by Galloway *et al*. (1989).

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

* Reproduced exactly from Galloway *et al*. (1989:609)

Komar (1998) studied decomposition in the colder climates of Canada, and found sizable variation in decay rates, where scavenging largely contributed to the dispersion of the remains and the destruction of soft tissue for terrestrial finds. Information about scavenging behaviors associated with the consumption of carcasses can assist in the reconstruction of the body's taphonomic history. Haglund (1997a, b) has shown that larger animals are attracted to decomposing remains, and contribute to the processes of decomposition and disarticulation in a predictable manner. Carnivores tend to consume the flesh of the face, feet and hands first (Mann *et al.* 1990). Haglund (1997a) describes the earliest scavenging as focusing on the face and neck, followed by destruction of the torso and partial or full removal of the upper and then lower limbs. As the remains continue to be strewn and skeletonized, canids tend to disarticulate all remaining joints, leaving only the cranium and bone fragments. During this process, remains tend to be strewn over large geographic regions and are often not recovered (Haglund 1997a).

Although insect activity was not considered, Komar (1998) did investigate mean monthly temperatures' concurrence with the postmortem interval, and found that summer decay rates progressed more rapidly than winter decay, a trend that is consistent with other literature (Bass 1997; Galloway 1997; Galloway *et al.* 1989; Rodriguez and Bass 1983). Skeletonization in Canada happened in less than six weeks during the summer and in less than four months during the winter (Komar 1998:59). In Arizona, outdoor skeletonization (50.0% or more of the remains) was found to occur between two and nine months after deposition (Galloway *et al*. 1989), and during the summer in Tennessee, skeletonization may be achieved between two and four weeks (Mann *et al*. 1990).

Although the time ranges are longer for outdoor decomposition in the winter, the composition of the remains are approximately the same for both seasonal extremes (Galloway 1997; Galloway *et al*. 1989). In other words, the body passes through the same taphonomic changes in both environments, but they develop and disappear at differing rates.

Skeletonization is a process of advanced decompositional change that is characterized by the absence of soft tissue. While the aforementioned studies show that skeletonization proceeds at different rates among different environments, it is not clear as to whether or not the sequence of skeletonization was the same. Roksandic (2002:102) discusses Dirkmaat and Sienicki's 1995 presentation on the sequence of skeletonization for surface depositions when carnivore activity is absent. They found that Diptera larvae infestation of the facial region led to skeletonization first occurring in the cranium. In conjunction with the loss of soft tissue in the cranial region, the clavicles and sternum were next to become skeletonized. Dirkmaat and Sienicki also found that the thoracic and abdominal regions tended towards skeletonization before the pelvic region (Roksandic 2002:102). Upper extremities usually skeletonized before the lower extremities, and feet were the last area of the body to lose their integrity. When sun exposure was present, they found that portions of the skin would mummify rather than skeletonize.

Disarticulation of skeletal elements typically occurs as a result of skeletonization. Haglund (1993:812) describes, "The sequence of disarticulation is influenced by the nature and relative anatomical position of the joint involved." Disarticulation of joints is a function of the joint flexibility and the ligament attachments, where more flexible joints are likely to disarticulate before less flexible joints or those with strong ligament attachments (Haglund 1993, 1997a). Roksandic (2002:103-104) summarizes Duday's (1985) work and explains that there are "three types of articulations: weak articulations with a small volume of soft tissue attached to them (extremities), weak with an important volume of soft tissue attached (trunk), and persistent articulations." Joints with little flexibility and more rigid articulations such as the vertebral column tend to remain intact longer than pliant joints such as the "radio-carpal, tibial-tarsal, elbow, and knee joints (Haglund 1993:812)." However, disarticulation across cases does not follow a straightforward pattern. Roksandic (2002:104) describes:

> "the relationship of joints to portals of entry for insects, accessibility and feeding behavior of scavengers, the position of the body and types of surfaces the remains rest on (inclines for example) have to be included as well. Again, as with decomposition rate, disarticulation sequences are highly environmentally and micro environmentally specific (Haglund, pers. commun.)."

With this and other examples, Roksandic (2002) discusses the variation in the sequence and rate of skeletonization and disarticulation within varying environments, and thereby underscores the environmental particularism of taphonomic changes. These studies exemplify the disparity in decomposition rates that are due to the variation in environmental contexts, and specifically, temperature and humidity. Research on outdoor, terrestrial locations has yielded exceptionally useful information for both application and for the development of the field of forensic taphonomy. However, there are clearly gaps in the literature where more research is needed on this topic. Although the data for the current study does not possess many cases of outdoor finds, outdoor surface cases were analyzed separately and the results were compared with Bass' (1997) results in an effort to provide a meaningful contribution to location-specific analyses of human decay.

Subsurface Locations

It has been shown that buried bodies decay more slowly than bodies deposited on the ground's surface (Mann *et al.* 1990; Rodriguez 1997; Rodriguez and Bass 1985). The aforementioned authors found that burial depth was one of the most pertinent variables affecting the pace of decomposition in subsurface burials, where deeply buried bodies decompose more slowly than those placed in shallow graves. Rodriguez and Bass (1985) conducted experimental research in Tennessee where bodies were buried with thermometer probes at depths ranging from 1 – 4 feet. They discovered that soil depth was paramount in subsurface decomposition rates because it retarded two major extrinsic factors: insect access to the remains and temperature increase or fluctuations.

Rodriguez and Bass (1985) determined that Diptera could not access remains buried at 2 feet below the surface, but could gain entry to the remains when bodies were buried only one foot deep. For cadavers only one foot subsurface, decomposition odors permeated the soil and attracted Dipteras (Rodriguez 1997). The flies were detected maneuvering cracks in the soil in attempts to reach the carcass and were also observed depositing eggs on top of the soil and within its crevices (Rodriguez and Bass 1985:848).

Diptera activities appeared to become more prevalent right after heavy rainfall (Rodriguez 1997; Rodriguez and Bass 1985). When the larvae hatched, they migrated through the soil until they reached the remains; thus the burial depth and the degree of soil compaction above the carrion are important considerations for insect access in subsurface depositions (Rodriguez 1997).

Thermometers that measured the temperatures of each body during decomposition showed that soil acts as a mechanism for insulation of buried carrion. Rodriguez and Bass ascertained that "(s)oil temperatures and the fluctuation of those temperatures were found to decrease with increasing in soil depth (1985:849)." In fact, daily temperature fluctuations only occurred in burial depths of one foot. Beyond one foot subsurface, a cadaver is relatively insulated from daily temperature trends. These observations indicate that the deeper a body is buried, the slower the rate of decomposition (Rodriguez 1997). This correlation is reflective of temperature as the most important factor in decompositional change (Mann *et al*. 1990).

The differential susceptibility to surface temperatures by grave depth was also reflected in another finding. Rodriguez and Bass (1985) found that bodies increased in temperature relative to the ambient soil. Further, burial depth affected the difference between body temperature and soil temperature as well as the time needed to achieve that difference. The increase in temperature of a deceased organism is directly related to "the high metabolic rates of dipterous larvae and bacteria (Rodriguez and Bass 1985:850)." Given that insects are restricted from buried remains, it appears that the increase in carrion temperature is primarily a result of bacteria involved in putrefactive processes.

The authors note that due to “lower environmental temperatures and fluctuating oxygen and pH levels, bacterial action should be somewhat decreased (Rodriguez and Bass 1985:850).” This hypothesis was supported in that the temperature differential between buried remains and the ambient environment were lower than they were for previously examined surface remains. Additionally, bodies located closer to the surface had higher mean temperature differentials (one foot = 10˚C) than the cadavers that were placed in deeper graves (4 feet = 3.4˚C).

When the bodies used for Rodriguez and Bass’ (1985) study were examined, it was found that the degree of decomposition clearly correlated with the depth of burial; by inference, the degree of decomposition was also correlated with the degree of insect predation and temperature exposure. An association between deep burials and moist environments was also identified and has been observed elsewhere (Galloway 1997:147; Rodriguez 1997:460). Plant growth near subsurface burials can also contribute to tissue breakdown (Rodriguez 1997; Rodriguez and Bass 1985). Plant growth may be catalyzed by the autolytic release of substances that act as fertilizer. Shallow graves tend to have increased plant growth because the roots are less disturbed when the grave is dug, and the remains are in closer association with the plant roots. Thus, carrion deposited in shallow subsurface locations may decompose more quickly when local foliage has time to reoccupy the burial location. Based on these findings, it is clear that burial depth is an essential extrinsic consideration in estimation of the postmortem interval for subsurface depositions.

Aquatic Locations

Bodies of water where human remains can be discovered vary "radically with respect to temperature, depth, salinity, oxygenation, or current. Features of shores, bottoms, and life forms are also variable (Haglund and Sorg 2002b:202)." This variability of water environments will differentially affect the remains in question. The discussion here is limited to the changes associated with all or fresh water depositions, as freshwater was the context of interest in this analysis.

Rodriguez (1997:461) writes that the decelerated rate of decay for bodies in water is primarily a result of cooler temperatures and less insect activity. A body with air in the lungs may float initially but is likely to sink in fresh waters as the lungs depress (Haglund and Sorg 2002b; Rodriguez 1997; Spitz 2006). Clothing with trapped air can assist in flotation of the body and prolong the interval before the body sinks (Spitz 2006). After a body has sunk below the waterline, it begins the normal processes of decomposition. The buildup of putrefactive gases within the gastrointestinal tract and lungs will cause the body to float and eventually resurface (Rodriguez 1997). When putrefaction occurs, "gas may accumulate and expand the volume of body cavities to a point where internal pressure overcomes external water pressure, the body expands, and the body becomes buoyant (Haglund and Sorg 2002b:205)." A bloated corpse can become so buoyant that putrefaction has been known to cause flotation even when the body is rigged to an additional 100 pounds (Spitz 2006).

The length of time needed for the body to resurface is primarily dependent on the temperature of the surrounding water. Warm temperatures will cause a body to float relatively quickly and cool temperatures will prolong the interval needed to accumulate enough decompositional gases to cause flotation (Haglund and Sorg 2002b). Spitz (2006:853) and Rodriguez (1997:461) claim that flotation in warm water will occur within 2 to 3 days, while flotation in cold water may take weeks or months. Water temperature declines with depth and so the rate of decay is also affected by the depth of the carcass within a body of water (Rodriguez 1997). This association between water temperature and flotation is a direct reflection of the importance in temperature over time as it affects the rate of putrefactive processes.

Bodies often float in the position where the face, stomach and appendages are submerged, while the back and buttocks may be exposed above the water line (Haglund and Sorg 2002b; Rodriguez 1997; Spitz 2006). Extensive bloating of the abdomen can also cause the body to float on its back with the bloated abdominal region protruding above the water line (Haglund and Sorg 2002b). The position of the remains is paramount to the decomposition process, as it often leads to different portions of the body being exposed to different environmental factors. Bodies floating in water will present typical indicators of decomposition, such as bloating and insect infestation (Mann *et al.* 1990), yet the taphonomic affects that manifest and their location on the body is dependent on the position of the body. Underwater portions of the body are likely to exhibit lividity (Rodriguez 1997), fungus growth, extensive skin slippage (Spitz 2006), and are most susceptible to postmortem abrasions and scavenging by underwater species (Haglund and Sorg 2002b). Above the water line, sun exposure can cause the skin tissue to desiccate and mummify if the environment is dry (Haglund 1993; Spitz 2006).

Additionally, tissues exposed above the water line are likely to become colonized by Dipteras (Rodriguez 1997), although it has been shown that the larvae can migrate down below the water line once they have been established on the corpse (Haglund and Sorg 2002b).

As decomposition continues and putrefactive gases are released, the body eventually loses its buoyancy and again sinks to the bottom of the water source. Here, the cadaver may be in a position to undergo adipocere formation or aquatic scavenging. Adipocere formation typically occurs in warm waters but has also been known to occur in surface and subsurface burials (Fiedler and Graw 2003; Manhein 1997). Where it was once thought that adipocere only formed in moist environments, it has since been found that a body's fluids may provide enough moisture to facilitate the development of adipocere (Manhein 1997:472-473). Mellen *et al*. (1993) found that in warmer waters, adipocere developed within two to three months, whereas in cooler waters, it developed within twelve to eighteen months. Adipocere severely retards the rate of decomposition, yet there is no clear set of circumstances under which adipocere will form.

Aquatic scavenging can play an important role in the removal of soft tissue within aquatic environments (Haglund 1993). Skeletonization in water roughly mirrors that of terrestrial based remains, whereas disarticulation of underwater remains creates a different pattern than that of terrestrial carrion. Generally, the body parts that are first to disarticulate are the "hands and wrists, mandible, and cranium," followed by "the lower legs, forearms, and upper arms (excluding the pectoral girdle; Haglund 1993:811)." Clothing tends to impede the disarticulation process for bodies in water. Differential disarticulation patterns for water and terrestrial environments reflect the different environmental forces interacting with the carcass.

The decomposition profile for aquatic depositions hints at a unique and complex set of factors acting upon the remains. It is clear that anthropophagy and temperature are important factors in setting the tempo for human decay, yet these variables are manipulated quite differently in water environments than what may be found in terrestrial settings. Of particular interest is the differential exposure of submerged and air exposed portions of the remains. While this study's sample of aquatic depositions was small, taphonomic trends were identified and compared with the trends discussed here.

Indoor Locations

Anthropological studies have been conducted on bodies decomposing in enclosed repositories but research on this environment is relatively uncommon (i.e., Galloway *et al*. 1989; Goff 1991; Schroeder *et al*. 2002; Voss *et al*. 2008). Galloway and colleagues (1989; Galloway 1997) performed a retrospective study on human decay in southern Arizona, where they identified varying patterns of decomposition between indoor and outdoor environments. The authors ascribed the differing patterns of decay to the contrast in moisture between closed and open settings. They discovered that open environments in Arizona are characterized by hot, arid conditions that often lead to rapid bloating and long periods of tissue desiccation and mummification. Due to the heat and aridity, outdoor finds were often preserved for longer periods and hence lingered longer in the later stages (Galloway *et al*. 1989). Bodies deposited in closed structures decayed more slowly during the initial phases of decomposition, but progressed to skeletonization rather quickly.

Cadavers discovered in outdoor settings displayed bloating between the second and fifth days, with skeletonization not occurring until approximately eight months postmortem (Galloway *et al*. 1989). In contrast, enclosed remains usually exhibited bloating between the third and seventh days, but often achieved skeletonization by the fourth month postmortem. One case of indoor decomposition during the late summer demonstrated that over fifty percent of the body became skeletonized within a mere seven days (Galloway *et al*. 1989). The authors noted that enclosed remains were less prone to mummification but rather, commonly underwent "moist decomposition," which facilitated the expedited exposure of bones in the later part of the process (Galloway *et al*. 1989: 613, 615). When mummification did occur, it took approximately two weeks longer than outdoor mummification (Galloway 1997).

There is also some question as to how accessible bodies are to insects when they are located within structures and containers. Haskell (2006:170-171) notes that there are several problems associated with estimating insects' contribution to decomposition within enclosed structures. If the structure is well sealed, the decomposition odors that attract insects may never emanate outside of the structure. If insects do detect the odors of decay, the structure may prevent them from being able to access the body. When insects have successfully accessed the body, there may be differences in temperature between the enclosed and the outside environment. This temperature disparity as well as restricted access to the remains could lead to differences in the rates of insect development and thus introduce error into the estimation of the postmortem interval.

Goff (1991) performed a comparative study on human remains found indoors as opposed to outside in Hawaii, where he focused on the species of insects that were shared by both habitats. Goff also found that insects' access to remains caused a disparity in decomposition rates between indoor and outdoor environments. Beetles were almost always absent from indoor settings, which resulted in a different pattern of species' colonizations and successions for the two environments.

Goff (1991) revealed that closed environments displayed the most diversity of insect species during the earlier decomposition stages (6 – 7 days), followed by a rapid decline. The outdoor carrion's colonization pattern differed from the indoor, in that outdoor carcasses possessed the most insect diversity amid the eighth through tenth days and retained a greater level of diversity throughout the remainder of the study (twenty one days). This may be attributed to the increased accessibility of outdoor deposition and the added presence of beetles, which tend to colonize remains during and after the "bloated" stage.

Goff (1991) also found that there were a greater number of fly species associated with indoor decomposition habitats, but that there was a greater number of species diversity, particularly beetle species, found within the outdoor decomposition habitats (Goff 1991). These results are directly oppositional to observations made from a case study in Germany, where a mummified male was discovered in his home and was almost completely skeletonized in less than five months (Schroeder *et al*. 2002). In this case study, the carcass was covered in beetles, their larvae, and empty larval casings. The body had rapidly become skeletonized, and the bones and mummified dermis possessed multiple defects that were caused by the necrophagous beetles and their larvae. The apartment conditions were conducive for mummification; the windows were closed and the heating system was turned to high. Mummified dermal tissue can prevent the infiltration and colonization of fly larvae, which tend to thrive on warm, humid soft tissues (Galloway 1997; Galloway *et al*. 1989). A small number of dead adult flies and empty pupae casings were discovered in the home, but there were not enough to imply that the flies had substantially contributed to the body's accelerated decomposition. In contrast, beetles possess strong mouthparts that are conducive for penetrating and consuming tough, mummified skin and even bone, and were likely the primary catalyst for the body's accelerated rate of soft tissue removal (Schroeder *et al*. 2002).

The results from Goff (1991) and Schroeder *et al*. (2002) research were consequences of the accessibility of indoor finds to flies and beetles, the primary insects involved in cadaver decomposition. Although there was no quantification, Goff (1991) noted that there seemed to be larger numbers of insects associated with outdoor cadavers, and that bodies found on the sixth floor or above were not affected by insect activity (Goff 1991:749). This study demonstrates that enclosed remains are less accessible to insects and virtually inaccessible to beetles, whereas the observations made by Schroeder *et al*. (2002) indicate that beetles do play a large role in the removal of soft tissue for enclosed carrion. The disparity between the two studies may result from the very different environments where each study took place, and also the case study may not be representative. However, both analyses indicate that environmental conditions associated with decomposition in differential locations likely leads to a disparity in the numbers of insects, rates and patterns of colonization, and the rates of decomposition.

The contribution of animal scavenging to indoor decomposition has not been quantified. Yet, domesticated pets that have access to human remains will consume soft tissue and accelerate the decomposition process (Galloway *et al*. 1989; Perper 2006; Steadman and Worne 2007). Steadman and Worne (2007) looked at a case study of two large pet dogs that were locked away in the home of a woman who lived and died alone. The woman's body remained in the home with the dogs for approximately 4 weeks. When she was discovered the only remaining biological remains were her hair, a portion of the skull and splintered fragments of long bones. Importantly, there was no evidence of decomposition odors or fluids in the carpet. In spite of the presence of dog food, it appears that the dogs consumed her flesh fairly soon after death. Interestingly, the authors found that while canid scavengers in outdoor settings may strew disarticulated remains over a large geographic area, canine scavenging in the home was confined to a small area in one room. It was of interest to see how frequently the phenomenon of scavenging by pet dogs was observed for depositions within enclosed spaces. Understanding the contribution of canine and feline scavenging towards enclosed space decomposition could also prove useful in estimating the postmortem interval for people who have died alone in their homes and whose bodies have been partially consumed by their pets.

There is a need for more research that quantifies the contribution of animals, insects and moisture to decomposition within enclosed locations. Mann and colleagues (1990) noted that insects are responsible for eliminating the majority of soft tissue and consequently, insects' access to remains was rated as the second most important variable in estimating the rate of decay. In the Galloway *et al.* study, authors noted that insect activity was influenced by "location of the body, seasonal weather, and accessibility of the soft tissues (1989:607)." They found that indoor deposition often led to a more moist decay than would be experienced outdoors. Although Galloway *et al*. (1989; Galloway 1997) addressed the differing rates of decay between open air and closed locations, whether or not insect access was lessened or heightened for indoor locations was not addressed. Galloway *et al*. (1989; Galloway 1997) found accelerated rates of decay for enclosed remains, whereas Goff (1991) did not address the differential rate of postmortem transformation. However, Goff's (1991) study suggests that insects do not easily access enclosed carrion, and hence the pace and pattern of the decomposition process is altered. Although only a case study, the Schroeder *et al*. analysis indicates that the types of insects that can access indoor remains is geographically specific. The accessibility of indoor bodies to insects and consequently the prominence and effects of insect activity in the decomposition process of protected bodies remain unknown. This thesis addressed the question of if and how insect and animal activity affect indoor decomposition by examining the prevalence of anthropophagy for enclosed locations.

Vehicle Locations

The disparity in insect access and temperature between enclosed vehicle and outdoor carrion environments (Haskell 2006) must also be considered. For a body contained within a vehicle on a sunny day, temperatures inside the vehicle may be 20˚ C higher than the outside temperature (Haskell 2006:170). Voss and associates (2008) performed an experimental analysis using pig carrion to compare the rates of decay within vehicle environments to those in a nearby surface location in Australia. For this study, five stages of decomposition were utilized. These stages basically corresponded with Bass' (1997) stages. However, Bass' advanced stage was separated into "wet decomposition " and later, "dry decomposition (Voss *et al*. 2008:24)." The authors measured the temperature of the carrion throughout the experiment and compared the PMI days needed to achieve each stage.

Voss and colleagues' findings suggest that bodies deposited in the driver's seats of sealed vehicles decompose at a faster rate than outdoor surface depositions. They discovered that increased vehicle temperatures catalyzed the rate of decay so that "the overall progression of decomposition through the identified physical stages was 3 – 4 days faster within the vehicle environment than in a surface decomposition situation (Voss *et al*. 2008:30)."

Insect succession patterns in vehicles mirrored that of outdoor settings, where flies (Calliphoridae) were first to occupy the remains and beetles (Coleoptera) were subsequent to fly colonization. However, there were differences in the timing for insect succession between the two settings. Calliphoridae were found interacting with outdoor carrion within the first hour of unveiling whereas flies were not seen in contact with vehicle carrion until 16 – 18 hours after deposition (Voss *et al*. 2008). Correspondingly, Coleoptera were found on outside cadavers when they were undergoing the bloated stage and their larvae were identifiable during the wet stage of decay. For carrion located within vehicles, beetles did not obtain access to the remains until they were within the wet stage of decomposition. These observations demonstrate that insects can access bodies deposited within a sealed vehicle. The authors presumed access through air vents (Voss *et al*. 2008:30). Yet, the delayed colonization of carrion in vehicles indicates that a vehicle does present a human influenced barrier that insects must manipulate in order to gain entry.

The Voss *et al*. (2008) study suggests that cadavers deposited within vehicles decompose at an accelerated rate due to increased temperatures, even though insect infestation is delayed. Associated with this increased rate of taphonomic change, the bloat and dry phases lasted for a shorter period of time. However, the wet decomposition phase was roughly paralleled in time span between outdoor and vehicle cases. Voss *et al*. (2008) found that the wet phase was when insect activity was most prevalent and this is also when the temperature of the carcass was at its highest. They concluded that the temperature of the body rather than ambient temperature "was a major contributing factor driving this stage (Voss *et al*. 2008:30)." This experiment suggests that vehicles constitute a unique environment due to their associated high temperatures; yet the challenges presented to insects that wish to access the remains parallels those identified for indoor settings. For the purpose of this analysis, indoor and vehicle depositions were grouped together based on the similarity in epidemiological barriers to the remains in conjunction with small sample sizes for vehicular depositions. While grouping of these two contexts has the potential to confound some factors, it also allowed for a more robust statistical exploration of the multiple factors that set the tempo for decay within enclosed settings.

Recapitulation

Most research that have centered on estimating the rate of decay have only focused on extrinsic and intrinsic factors related to outdoor, terrestrial depositions. Importantly, all of the claims reviewed here are not quantified. There is no predictive value and there are no error rates, which could raise issues of admissibility for courts of law (Christensen 2004; Christensen and Crowder 2009). Further, while Bass (1997) provides a comprehensive description of the general changes that transpire with decomposition, they are based on alterations that occur in the outdoor environment of Tennessee. What does this say about the postmortem interval for bodies that decompose in sheltered environments or other geographical settings? A review of the literature shows that there is a scarcity of research on the decomposition of remains found in automobiles, houses, or other structures (Galloway 1997; Galloway *et al*. 1989; Goff 1991; Schroeder *et al*. 2002; Voss *et al*. 2008). Yet, an analysis of the Nebraskan autopsy records show that many people who die and go undiscovered for any length of time often expire in their homes. Clearly, there is a great need for incorporation of an anthropological model in studies of unaccompanied deaths as well as environmentally specific data on decomposition in enclosed environments. Legal requirements necessitate quantification of the potential or observed error inherent in any method that is to be used in cases of forensic significance (Christensen 2004; Christensen and Crowder 2009; Grivas and Komar 2008), and so future trajectories should place emphasis on statistical methods that can meet these requirements. Anthropologists' holistic approach places them in a strong position to provide such a comprehensive model.

This study employed an anthropological model to look at unaccompanied deaths and their subsequent postmortem intervals. The purpose of this project was to establish the intrinsic, extrinsic and epidemiological factors that most influence the rate of decomposition in enclosed spaces. Outside surface, subsurface and aquatic finds were limited in this study, but they were analyzed for factors that affect the rate of decomposition within each subset. For enclosed locations, this study identified trends in temperature and how it affects the decay process in Nebraska. The question of whether necrophagous organisms' have access to remains was investigated to determine if this variable could be used to predict rates of decomposition, and to assess whether the presence of insects affects the rate of decomposition differently in enclosed locations.

The results were compared to Bass' stages (1997) of decomposition to assess the appropriateness of this model to the traditional decomposition stage approach. In addition, local weather data were used to calculate the accumulated degree days for each case. ADD for this study are defined as the sum of all daily mean temperatures above 0˚ C that comprise the postmortem interval time span (Megyesi et al. 2005). Ranges of ADD were paralleled with rates of decomposition discovered in the data and were used to develop a predictive model for the quantified rates of decomposition for estimation of the postmortem interval in enclosed locations. Ultimately, this research aimed to implicate ADD as a way to provide standardization to the model that enables it to be mobilized globally.

Chapter 3

Materials and Methods

Research Setting

The data were collected at the Nebraska Institute of Forensic Science, Inc. (NIFS), located in Lincoln, Nebraska, in the central region of the state. It is a nonprofit institution that performs forensic autopsies and other death investigation services to a large part of Nebraska. The NIFS serves as the Forensic Pathology division of the Coroner's Office in Lancaster County (which encompasses Lincoln) and is affiliated with the Department of Pathology, Creighton University School of Medicine in Omaha, Nebraska, as well as several other universities located outside of the state (Nebraska Institute of Forensic Sciences 2003). The institute provides certification programs, annual seminars and a variety of internships aimed at training members of the medicolegal community, with a particular focus on recruitment of qualified individuals from minority groups and women. Their emphasis on teaching and training is manifested through an abundance of opportunities in research initiatives and service opportunities at the institute as well as among many other like-minded organizations with which they have established affiliations. The author was granted an internship at NIFS as an opportunity to engage in training and research for the production of a Master's thesis.

Materials

Research on unaccompanied deaths was conducted retrospectively. The author and Casey Anderson, B.A collected the data. The data were collected from various formal documents, such as police and autopsy reports, as well as entomological and anthropological records and police scene photographs. Most data were collected directly from the autopsy and police reports, and were supplemented by police scene photographs and specialists' reports, when available. The retrospective nature of the data presupposes that some data are missing and as a consequence sample sizes vary among analyses.

The data consisted of eighty-six individuals who died in variable environments within the state of Nebraska and who were autopsied between the years of 2003-2008. The individuals used for this study were selected based on documentation that produced an estimate of the PMI, with the expectations that they will yield information about the rate of decay. The postmortem interval was estimated from the time decedents were last known to be alive until when they were discovered. Consequently this range may be an over-approximation for most cases. When possible, this interval was refined based on supplementary information.

Protocol Description

The full protocol that was used to collect data included in this analysis is in Appendix A. The attached protocol is extensive and not all of the original variables were pertinent to the data analysis presented in this thesis (Kimmerle 2008). This protocol is part of ongoing research into decomposition in other geographical areas conducted by the

Bioarchaeology and Forensic Anthropology Laboratory at the University of South Florida. Table 3.1 summarizes the variables used in this study according to the model employed. The protocol was designed to elicit information on the epidemiology of solitary deaths and ask questions about the decedent demographics and perimortem circumstances (cause and manner of death) as well as about factors that affect the rate and extent of taphonomic change (extrinsic and epidemiological taphonomic factors), and the state of the remains when they were discovered (intrinsic taphonomic effects).

Table 3.1—Anthropological Model for Research in Human Decomposition.

Intrinsic Factors	• Age, sex, ancestry, weight	
(Biological)	• Decomposition stage (Bass 1997)	
	• Skeletonization	
	• Biochemical changes	• Algor, livor and rigor mortis
		• Skin slippage and bullae
		• Marbling
		• Bloating
		• Green discoloration
		• Purge fluid
		• Mummified skin
		• Adipocere
		• Decomposition odor
		• Mold growth
		• Decompositional fluid stain
		• Postmortem blood clotting
		• Brain, ocular and organ decomposition
	• Cause of death	
	• Injuries	
Extrinsic Factors	• Context (i.e., outdoor near-surface)	
(Environmental)	• Environment	• Location
		• Sun exposure
		• Temperature, Season
		• Insect or animal scavenging
	• Time (days)	
	• ADD (temperature over time)	
Epidemiological Factors	• Manner of death	
(Cultural/ Behavioral)	• Environment (of human influence)	• Type of weapon used
		• Type of structure (i.e., hotel room, vehicle)
	• Context (of human influence, i.e., indoor)	• Windows open/closed
	• Container (i.e. carpet, blanket)	• AC/Heat (also type of device used)
	• Deposition surface	• Location (within home or vehicle)
	• Clothing	
	• Postmortem modification (of human influence)	
	• Postmortem movement of body	
	• Person who discovered the body	
	• Burial factors (of human influence)	
	• Embalming, clandestine burial	

Intrinsic

Data were collected on demographic factors, such as sex, age, estimated ancestry, and whether or not the subjects were obese. Demographic data were collected to reveal trends in the demography of persons who tend to die alone and go undiscovered for extended lengths of time. Ancestry was originally recorded by police officers and the pathologist at NIFS and may not always accurately reflect an individual's self-perception of ancestry. The protocol also asked for the cause of death and whether or not any injuries were incurred around the time of death. Perimortem injuries were considered as a potentially important variable in the assessment of the role that insect necrophagy plays in the rate of soft tissue removal.

In the section labeled "Decomposition Stage Data," each set of remains was classified into the stages of decomposition outlined by Bass (1997). Bass' stages were constructed based on his experience with decomposing remains in an outdoor environment in Tennessee, and some of his observations differ from those found in this data set. Also, Bass' (1997) stages do not reference some of the earlier changes, such as rigor mortis and lividity. Therefore, the data collectors chose whatever stage "best fit" the description of the body. In addition, the assignment of each observation to one of the phases was supplemented by presence/absence questions that considered individual taphonomic effects, such as mummified tissue.

Extrinsic

The protocol was geared towards revealing information related to the role that necrophagous activity plays in taphonomic change (refer to "Scavenging Activity" in Appendix A). These questions centered on the types of animals and insects that had access to human remains in each environment. The species of insects were recorded when the information was available. This consideration of necrophagous activity was intended to facilitate the refinement of the postmortem interval estimation as well as enable an analysis of the disparity in insect activity among variable environments.

The times and dates of when a person was last known to be alive and when they were discovered were recorded as a way to estimate the postmortem interval. Temperature and climatological data for the PMI were recorded in the protocol (refer to "Temperature Data" in Appendix A). When noted, police reports were used to find information on the temperature of the scene at the time of when the body was discovered. To supplement this portion of the research, the average temperatures for each day within the PMI were derived from local weather stations. Weather data from local weather stations were obtained from the US Department of Commerce's National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC), "the world's largest active archive of weather data (National Climatic Data Center 2008)." NCDC's weather data are quality controlled and represent the best possible external source for weather data. These data were used to quantify the accumulated degree days for the PMI.

Epidemiological

The protocol recorded the manner of death and also elucidated information on the context of the burial location. This section addressed whether or not the remains were buried, what type of environment they were found in, what type of surface they decomposed on, and how exposed or covered the body was (refer to "Burial Factors" in Appendix A). The section titled "Indoor Factors" asked questions that were specific to an indoor environment and that would affect the temperature and exposure of remains to outside elements. Epidemiological questions also addressed body position, types of materials that made up the clothing, and how complete the remains were. These questions were considered important in understanding the availability of the remains to necrophagous activity, how greatly the body was exposed to environmental factors, and the relative degradation of clothing, which relates to the length of the postmortem interval.

Collectively, the protocol questions were used to identify what variables were useful in analyzing the demographic profile of people who die alone, exploring the variation in decomposition, and for predicting the accumulated degree days for enclosed environments.

Variables

The following is a description of all the variables used in the analysis, which is only a portion of the total amount of data collected. Categorization for who found the body included: friend, spouse, neighbor, police, stranger, landlord, family and other. As a way to describe the composition of the sample, the ages (in years) were divided into six categories: persons under the age of twenty, twenties, thirties, forties, fifties, and sixty or older. These age categories were selected as standard practice in paleodemographic research using skeletal data. However, the actual age distribution was used to test the relationship between manner of death and age. To test the relationship between cause of death and age, age categories of people within 30 – 49 years of age and people over 50 years of age were used. These categories were selected because they reflected the most common ages for death by drugs/alcohol and heart disease, which were the causes of death under investigation, and of particular interest in this research project.

The multifarious causes of death were separated into seven categories: drug or alcohol; infectious disease; carcinoma; heart disease; disease of the visceral organs; trauma; and carbon monoxide, carbon dioxide or fire related deaths. A person's death may be attributable to multiple causes, which may be physiologically linked in cause and effect and may be either acute or chronic contributors to cessation of life (Perper 2006; Adams *et al*. 2006). It can also be difficult or impossible to distinguish which physiological distress directly caused a person's death when there are multiple indicators and any one of which could have brought about the death, such as when a person sustained multiple injuries or suffered from both heart and lung disease. The purpose for categorizing the cause of death was to understand human behavior. Therefore, drug and alcohol related deaths were prioritized over all other categories. Infectious disease was prioritized over lung or heart disease, and heart disease was prioritized over all other visceral organ diseases. Manners of death employed in this analysis included: homicide, suicide, accidental, natural and undetermined.

In this study, autopsy recordings of actual stature and estimated weights were used to calculate estimations of body mass indices (BMI). The body mass index is a basic index that was used as an approximation of size based on proportions of weight to height, and was calculated with the formula below (3.1; Mielke *et al*. 2006:252).

$$\text{(weight in kilograms)}/\text{(stature in meters)}^2 = \text{BMI} \tag{3.1}$$

The purpose of including height, estimated weight and estimated BMI was to understand size and how size varies with decomposition rates in varied contexts.

The deposition of a corpse can provide information on the circumstances that led to one's death as well as establish environmental parameters that set the tempo for the rate of decomposition. Six main contexts of deposition were identified: outdoor surface, outdoor subsurface, submerged, within a vehicle, indoors, and exhumed/embalmed. An "enclosed context" referred to any deposition where the body was contained within a structure, and therefore enclosed contexts included both vehicles and buildings for this analysis.

As previously discussed about the protocol (Appendix A), investigators recorded each level of decomposition based on the description of Bass' stages that best fit the state of the remains (refer to Table 2.2). The postmortem interval was measured in days as a continuous variable and was always rounded up to the next whole day when there was overlap into part of a day. The PMI was also categorized into a time scale that reflects the time ranges associated with each decomposition stage in Bass' model. In this study, one modification to his PMI ranges was implemented; where Bass (1997) assigned the "dry" phase to a time range of one month to one year, this study broadened this PMI stage to any postmortem interval that was greater than one month. Therefore, the PMI categories were: first day, first day to first week, first week to first month, and beyond the first month.

The method for calculation of accumulated degree days was followed using Megyesi *et al*. (2005). Average daily temperature data for each postmortem interval were derived from NOAA's NCDC database and were then transformed into degree days. A degree day was defined as the daily average temperature of zero degrees Celcius or above. It was assumed that decomposition almost stops at zero degrees Celsius and so all daily temperatures at or below zero degrees were manually changed to zero. ADD were calculated by adding the degree days for each day represented within each PMI.

The variables considered for prediction of decay rates are listed in Table 3.2. All taphonomic effects were dichotomously categorized as present or absent except for skeletonization, which was categorized as ≤25.0%, ≈50.0%, ≥75.0%, or ≈100.0% skeletonized. All extrinsic variables were categorized dichotomously as present or absent except for environment during the PMI. Environment was categorized as: public space, private residence, along roadside, wooded area/field, hotel room, railroad tracks or other. The seasons were categorized dichotomously as spring/summer and fall/winter.

For burial factors, the rooms in the structure that were considered were the: basement, bedroom, bathroom, kitchen, living room, attic, garage and other. The surfaces of deposition identified were: dirt, mud, carpet, bedding, tile, linoleum, water, wood, porcelain, car seat/recliner/couch, metal, cement and combination. The containers included: blankets, caskets, carpet, vehicles and other. The percentage of body covered by clothing was categorized as: $\leq$25.0%, $\approx$50.0%, $\geq$75.0%, or $\approx$100.0%. The use of AC or heat and whether or not the windows were open or closed were categorized dichotomously.

Table 3.2—Intrinsic Variables, Extrinsic Variables and Burial Factors Evaluated for Each Context.

Intrinsic Variables	Extrinsic Variables	Burial Factors
• Rigor Mortis	• Environment	• Room in Home
• Livor Mortis	• Canine Scavenging	• Surface of Deposition
• Skin Slippage	• Rodent Scavenging	• Container
• Marbling	• Fly Colonization	• % of Clothing
• Bloating	• Beetle Colonization	• Windows Open/Closed
• Green Discoloration	• Seasons during PMI	• Use of AC/Heat
• Purge Fluid	• ADD	-
• Mummified Skin	• PMI	-
• Adipocere	-	-
• Decomposition Odor	-	-
• Postmortem Blood Clot	-	-
• Soil Stain	-	-
• Brain Liquefaction	-	-
• Skeletonization	-	-
• Organs Examinable	-	-
• Height	-	-
• Estimated Weight	-	-
• Estimated BMI	-	-

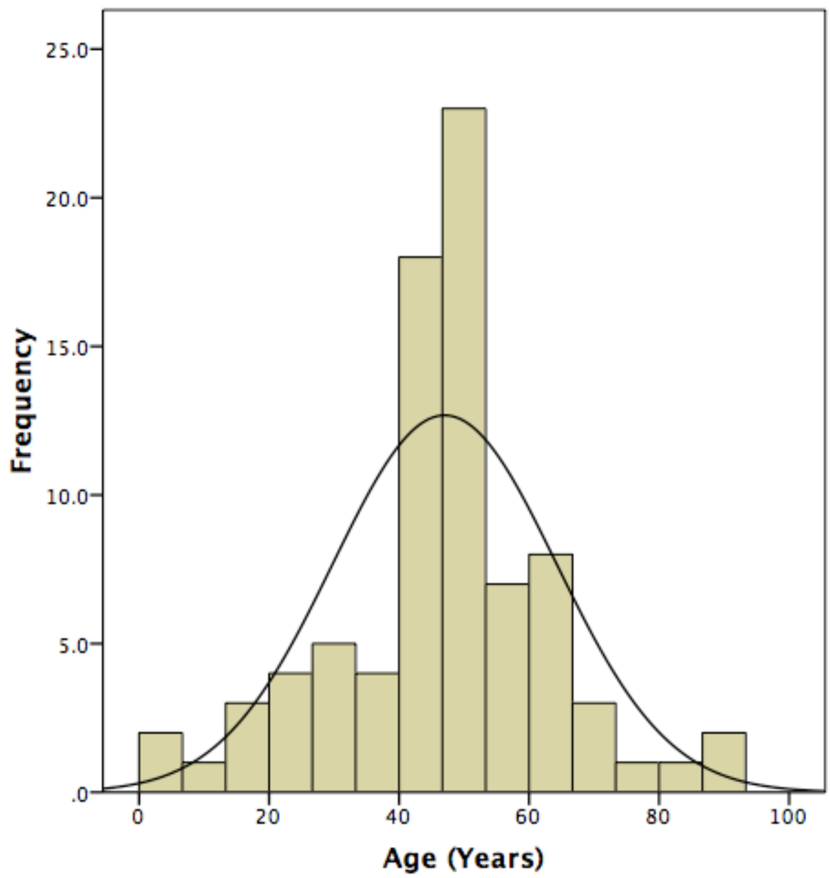
Sample

The data consisted of 86 individuals who died in variable environments in Nebraska. European Americans composed 88.4% (76/86) of the sample, while 11.7% (10/86) were descendents from other ancestral groups (Table 3.3). This sample included both males and females of various ages, although most were adults. There was a greater than 2:1 ratio for males to females, composed of 73.3% (60/86) males and 26.7% (23/86) females. Figure 3.1 demonstrates the age range for the entire sample. There were 82 adults and 4 subadults, whose ages ranged from two months to ninety-one years, with an average age at death of forty-seven years (*s.d.=17.20* years). The subadults in the sample included a seven year old, a fourteen-month and a two month old.

Table 3.3—Sample Sex and Ancestry.

Ancestry	Males	Females	Total
European-American	65.1% (56/86)	23.3% (20/86)	88.4% (76/86)
African-American	3.5% (3/86)	0	3.5% (3/86)
Hispanic	2.3% (2/86)	1.2% (1/86)	3.5% (3/86)
Asian	0	1.2% (1/86)	1.2% (1/86)
American-Indian	2.3% (2/86)	0	2.3% (2/86)
Bangladeshi	0	1.2% (1/86)	1.2% (1/86)
Total	73.3% (63/86)	26.7% (23/86)	100% (86)

Figure 3.1—Age Distribution of Complete Sample.



Statistical Methods

Demographic Profile of All Unaccompanied Deaths

To explore the relationship between manner of death and sex, two *Pearson Chi-squares of independence* were employed: one that only included natural and accidental deaths, and one that only included homicidal and suicidal deaths in conjunction with *Fisher's Exact Test*. To test for a difference in age structure at death between males and females, a *Mann Whitney-U* test was used. To test for a difference in age structure at death by manner of death, a *Mann Whitney-U* test was used. For this test, all manners of death except for natural were combined. To test for a relationship between cause of death and sex, a *Pearson Chi-square of independence* that only included heart disease and drug/alcohol related deaths in conjunction with *Fisher's Exact Test* was employed. A *Chi-square of independence* was used with *Fisher's Exact Test* to test whether or not age is independent of cause of death; this test only considered people in their thirties and forties and people over the age of 50 who died from drugs or alcohol and heart disease.

Chi-squares of independence were used to explore the relationship between manner of death and certain causes of death. Suicidal and accidental deaths were lumped together and compared to natural deaths to investigate the relationship between drug and alcohol related deaths and manner of death. A *Chi-square test of independence* with a *Fisher's exact test* was used to test the relationship between traumatic deaths and homicidal and suicidal manners of death. The demographic profile, causes and manners of death were also described for each context. Differences in PMI among manners of death were tested with a *nonparametric Kruskal-Wallis test*.

Taphonomy, the Postmortem Interval and ADD

To explore decomposition and time within the entire sample, the frequencies of each stage of decay and the PMI categories were explored. Descriptive statistics for PMI days and ADD were presented for each stage of decay. A *Spearman's correlation* was used to test how well Bass' model predicts the PMI for the entire sample.

Outdoor Near-Surface Subsample

The outdoor near-surface sample consisted of eight decedents. Descriptive statistics were provided for the postmortem interval. The frequencies of cadavers for Bass' decomposition stages and postmortem interval ranges were described. Individual taphonomic effects as well as prevalence and types of anthropophagy were identified and described by stage of decomposition and by time range.

Outdoor Subsurface, Aquatic and Exhumed Subsamples

The outdoor subsurface sample only consisted of two cadavers. There were three aquatic cases and three exhumed bodies. Exhumed bodies were not analyzed. Additionally, each decedent's postmortem intervals and associated taphonomic profiles were described as case studies.

Enclosed Subsample

In 79.31% (69/87) of the cases reviewed for this analysis were found within enclosed environments. An "enclosed context" referred to any deposition where the body was contained within a structure, and therefore an enclosed context included both vehicles and buildings for this analysis. Enclosed environments represented the largest sample and the thrust of this analysis and therefore merited further description. The causes and manners of death represented in this sample were discussed.

The relationship between rate of decay and season of deposition was explored with an *odds ratio*. The *odds ratio* was used to show the likelihood of decomposition before discovery in the spring/summer, when compared to the fall/winter. The frequency data were organized into a cross-tabulation and the following *odds ratio* formula was applied: *(ad)/(bc)*.

The relationship between PMI, ADD and decomposition stages were explored with *Spearman's correlations.* Bass' model was explored within the enclosed context and the frequencies for each stage of decomposition and associated postmortem interval ranges were explored. Descriptive statistics for each stage's postmortem interval and ADD were provided. A *Spearman's correlation* was used to test how well Bass' model fits with this sample's PMI.

Nonparametric Kruskal-Wallis tests were implemented to test for significant differences in PMI days and ADD among decomposition stages. To determine which stages were significantly different from which, *Mann-Whitney U tests* were employed.

All independent variables were explored to identify factors that may be useful in creating *linear multiple regressions* that predict PMI and ADD. To determine the profile of taphonomic change for enclosed environments, individual taphonomic effects and their relative frequencies were analyzed by stage of decomposition. Intrinsic taphonomic effects and their frequencies were also described by postmortem interval stages to begin looking for effects that may be good predictors of the PMI and ADD.

Odds ratios were used to determine the likelihood of the presence of certain intrinsic taphonomic effects after the first week of the PMI, when compared to the absence of intrinsic effects. Odds ratios were calculated for the presence of: marbling, bloating, green discoloration, mummification of skin, and brain liquefaction. The frequency data were organized into a cross-tabulation and the following *odds ratio* formula was applied: *(ad)/(bc).*

Subsequently, *Spearman's correlations* were utilized to determine if there were significant relationships among taphonomic effects, intrinsic characteristics of individuals during life, PMI days and ADD, with the purpose of identifying intrinsic factors that may be good predictors of PMI and ADD.

Extrinsic and epidemiological factors and their frequencies of occurrence were then explored to look for factors that potentially affect the rate of decompositional change. *Spearman's correlations* were used to determine if there are extrinsic and epidemiological variables that may make good predictors for PMI and ADD.

All continuous variables that were considered for model building were tested for normality with the *Shapiro-Wilk test*. PMI days were not used for model building as they were not normal and transformations were not successful. ADD were transformed to the log 10 of ADD (LogADD) and served as the dependent variable. Although ADD were transformed, the aforementioned correlations were presented to demonstrate that there is a real relationship among the potential independent variables and ADD.

Eleven potential independent variables were identified: skin slippage, marbling, bloating, green discoloration, mummified skin, decomposition odor, brain liquefaction, height, season of the PMI, percentage of body covered by clothing, and use of AC or heat. *Spearman's Correlations* between these variables and the LogADD were also presented. Issues of multicollinearity and failed transformations of continuous data that were not normal were discussed. Height and age were plotted against the LogADD to look for linearity.

A *linear multiple regression* analysis of the raw independent data and the transformed dependent variable was performed, which included: an analysis of the variance of Y ($\log_{10}$ADD), an adjusted R^2 that quantifies the amount of variation explained by the model, the t of all slopes that quantify how much variation is explained by each X, the equation that allows one to predict the effect of a predicted X value on the Y, the VIF and the TOL that quantify the correlation among X's. The procedures of forward selection, backwards elimination and stepwise regressions were used to determine what model was the best model.

The residuals for each model were analyzed to determine how well each model explained the variation of Y. The model was selected based on the following criteria: adjusted R^2, Mean Squares Error (MSE), Mallows' Prediction Criterion, the F ratio and the individual t scores. After the model was selected, the histogram and normal plot of the residuals were analyzed to look for variation that was unaccounted for by the model. The normality of the residuals was tested with the *Shapiro-Wilk test*. However, the residuals were not plotted against each independent variable because they were categorical. Lastly, the model was shown to be the best model possible for the data.

Chapter 4

Results

The results described in Chapter Four were divided into three broad categories that represent the three objectives of this thesis. The first section is the investigation of the demographic profile for people who die alone in the U.S. The second section is the identification of trends in the demographic profile of unaccompanied deaths by context. The third section is an inspection of taphonomic considerations within each context. For each context, the PMI, ADD, taphonomic factors and changes were described. For the enclosed setting, a predictive multiple regression model for estimation of ADD over PMI was constructed.

Demographic Profile of All Unaccompanied Deaths

In an effort to understand how the circumstances of an unaccompanied death may be linked to social context and a decedent's identity, the cause and manner of death were explored. Consideration was also given to the person who found the body. Of sixty-four cases where this information was known, decedents were most commonly discovered by law enforcement officials (28.13%, 18/64) followed by family members (21.9%, 14/64). There were no changes in this trend when the cases were sorted by sex.

Manner of Death and Sex

Of the eighty-five cases where manner of death was known (85/86, 98.84%), the most common manner of death was natural, followed by accidents (Figure 4.1, Table 4.1). For females, both natural and accidental manners of death were equally represented (for each, 34.8%, 8/23). For males, 62/63 cases had known manners of death. Natural deaths accounted for 53.2% (33/62) of all males whereas accidental only accounted for 17.7% (11/62). A *Pearson Chi-square of independence* including natural and accidental deaths revealed that sex is independent of manner of death ($X^2=3.389, df=1, p=0.066$). A *Pearson Chi-square of independence* that only included homicidal and suicidal deaths in conjunction with *Fisher's Exact Test* also showed that sex is independent of manner of death ($X^2=0.59, df=1, p=1.0$). Sex does not predict manner of death.

Sex and Age

Figure 4.2 demonstrates the age range for males and Figure 4.3 shows the age range for females. For males, the average age at death was 48.71 years (59/60, *s.d.*=16.04 years). For females, the average age at death was 42.62 years (23/23, *s.d.*=19.57 years). A *Mann-Whitney U* test revealed that there is no relationship between sex and age at death (*Mann-Whitney U=508.50, n=82, p=0.079*).

Table 4.1—Sample Manners of Death.

MANNER OF DEATH	SAMPLE SIZE
Homicide	10.5% (9/85)
Suicide	16.3% (14/85)
Accident	22.1% (19/85)
Natural	47.1% (41/85)
Undetermined	2.3% (2/85)
Total	98.8% (85)

Figure 4.1.—Sample Manners of Death.

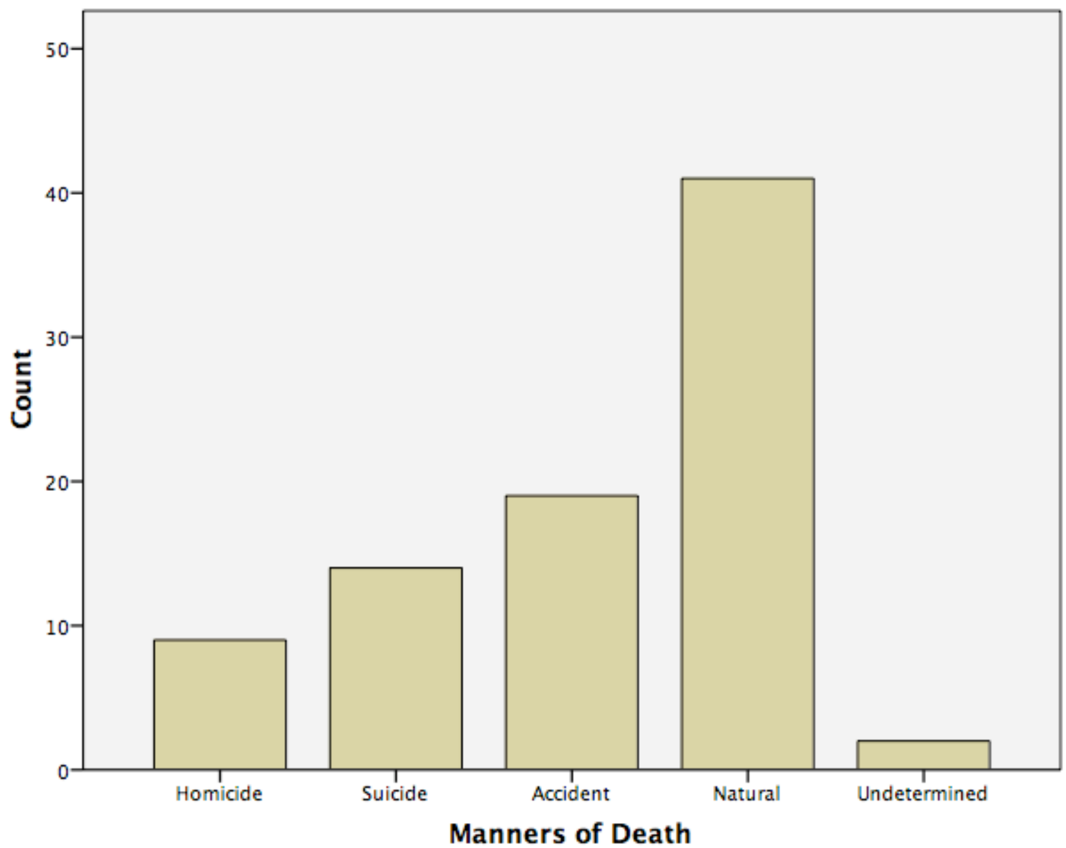


Figure 4.2.—Age Distribution for Males.

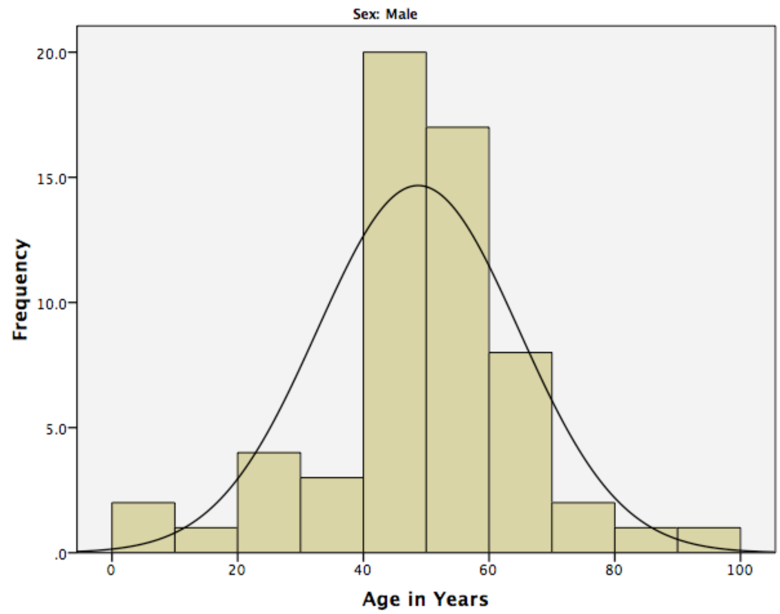
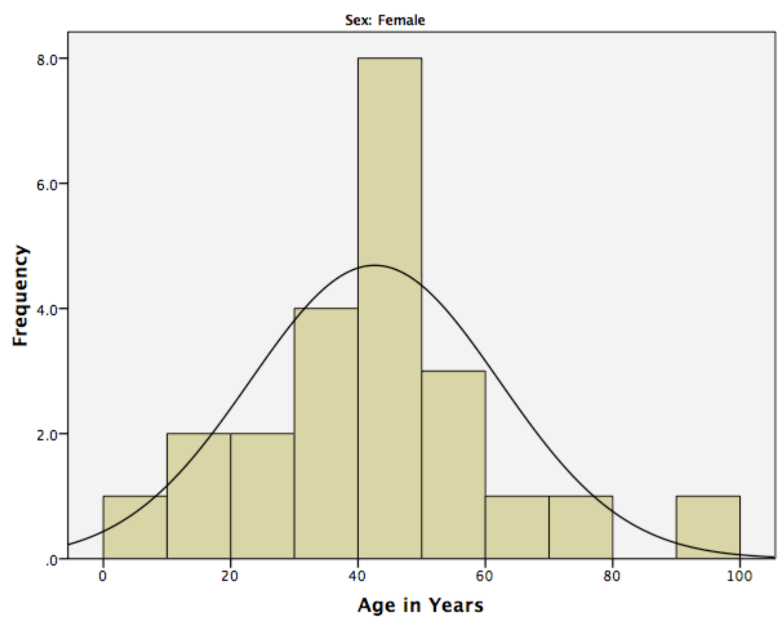


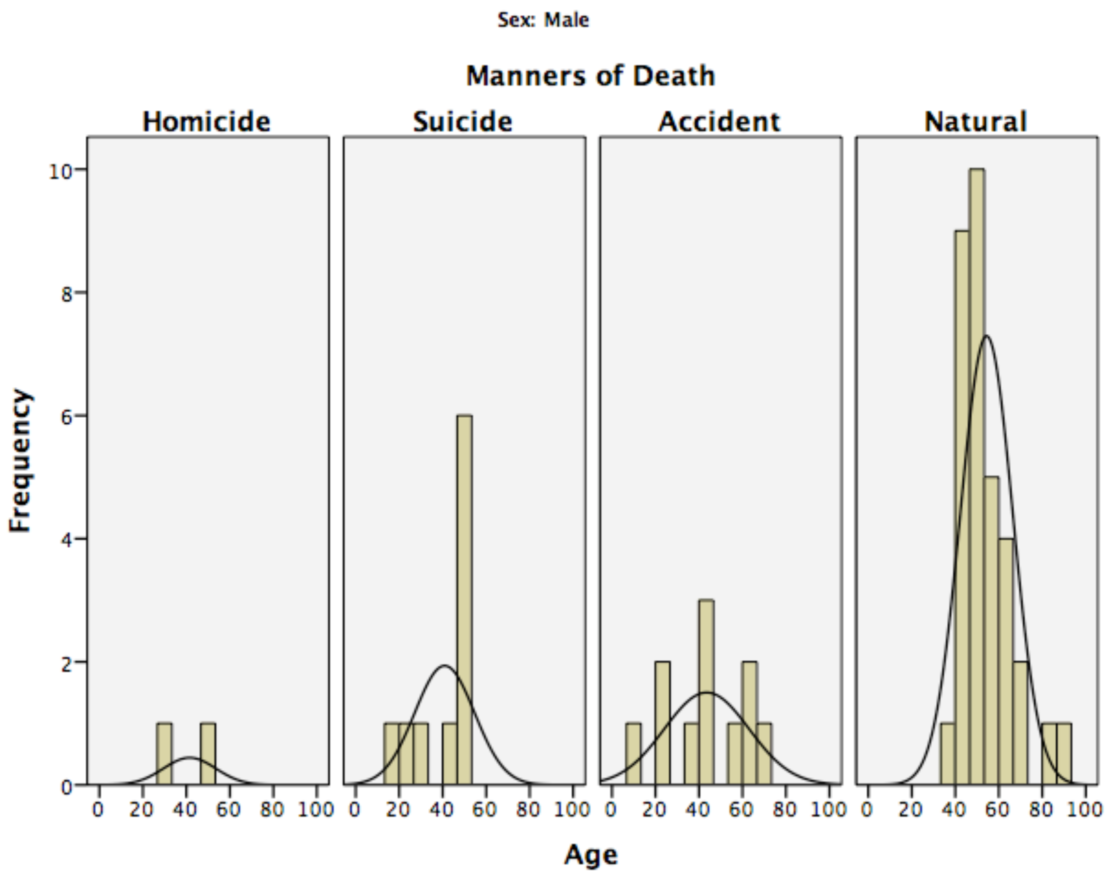
Figure 4.3.—Age Distribution for Females.



Manner of Death and Age

Figure 4.4 shows the age distribution for each manner of death among males and Figure 4.5 shows the age distribution for each manner of death among females. Table 4.2 show the frequencies for manners of death by age categories for the sample. Table 4.3 provides the descriptive statistics for age at death within each manner of death. The small sample sizes presented here limit the inferences that can be made from these data. However, the data show that persons under the age twenty years most often died from homicides and accidents (33.3%, 2/6 for each; Table 4.2). Individuals within the twenties age range most frequently died from suicide (33.3%, 2/6) and accidents (50.0%, 3/6). Persons within their thirties most frequently died from accidental (42.9%, 3/7) and natural (28.6%, 2/7) deaths, whereas those in their forties often died from natural causes (50.0%, 14/28) and suicide (25.0%, 7/28). Those persons in their fifties and over the age of sixty overwhelmingly died from natural causes (70.0%, 14/20; 78.6%, 11/14, respectively). All manners of death except for natural were grouped together and compared. A *Mann-Whitney U* test revealed that there is relationship between manner of death and age at death (*Mann-Whitney* $U=355.00$, $n=81$, $p \leq 0.000$).

Figure 4.4—Age Range by Manner of Death for Males.



* Undetermined deaths (n=2) not depicted.

Figure 4.5—Age Range by Manner of Death for Females.

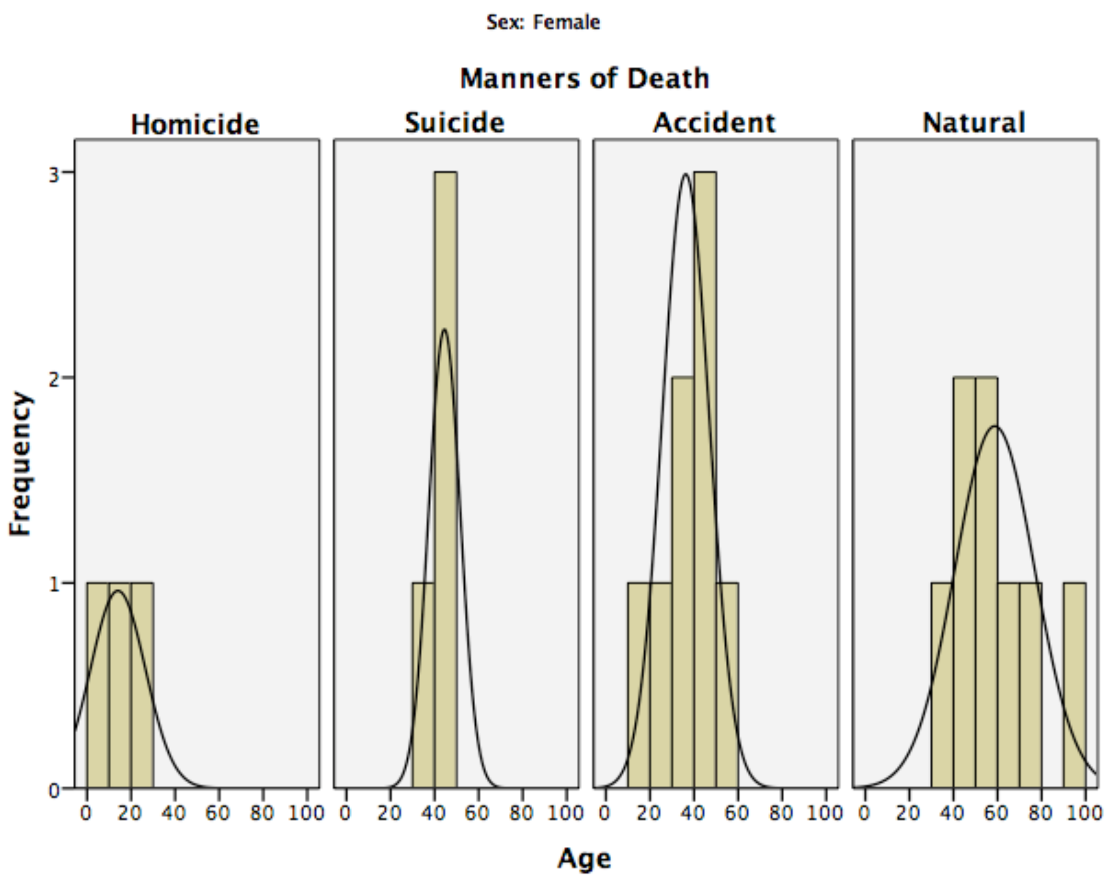


Table 4.2—Manner of Death by Age Range.

Age Ranges		Homicide	Suicide	Accident	Natural	Total
1-19	n	2/81	1/81	2/81	0	5/81
	% in Range	33.3	16.7	33.3	0	83.3
20-29	n	1/81	2/81	3/81	0	6/81
	% in Range	16.7	33.3	50.0	0	100
30-39	n	1/81	1/81	3/81	2/81	7/81
	% in Range	14.3	14.3	42.9	28.6	100
40-49	n	0	7/81	6/81	14/81	27/81
	% in Range	0	25.0	21.4	50.0	96.4
50-59	n	1/81	3/81	2/81	14/81	20/81
	% in Range	5.0	15.0	10.0	70.0	100
≥ 60	n	0	0	3/81	11/81	14/81
	% in Range	0	0	21.4	78.6	100
Total	Count	5/81	14/81	19/81	41/81	79
	Total %	6.2	17.3	23.5	50.6	97.5

Table 4.3—Descriptive Statistics for Age by Manner of Death.

Manner of Death	*f*	n	$\overline{X}$	s.d.
Homicide	6.2	5/81	25	18.48
Suicide	17.3	14/81	41.93	12.048
Accident	23.5	19/81	40.47	16.402
Natural	50.6	41/81	55.24	13.276
Undetermined	2.5	2/81	23.0	31.113

Cause of Death and Sex

Cause of death was known for eighty-two individuals (95.35%, 82/86). Figures 4.6 and 4.7 shows the prevalence of each cause of death for males and females, respectively. For individuals where cause of death was known, heart disease was the most prevalent cause of death (29.3%, 24/82), followed by alcohol or drug related and then trauma related deaths (24.4%, 20/82 and 23.2%, 19/82, respectively). Only one (n=1.2%) companionless death resulted from carcinoma. For males, the most prevalent cause of death was heart disease (40.4%, 19/47), followed by drug/alcohol related deaths (23.4%, 11/47). For females, drug or alcohol related deaths were most prevalent (45.0%, 9/20), and only three females died of heart disease (15.0%, 3/20). A *Pearson Chi-square of independence* that only included heart disease and drug/alcohol related deaths in conjunction with *Fisher's Exact Test* showed that sex is not independent of cause of death ($X^2=5.05$, $df=1$, $p=0.04$).

Cause of Death and Age Range

Figure 4.8 and Table 4.4 show the frequencies of causes of death for each age category. Table 4.5 lists the descriptive statistics for age within each cause of death. The small sample sizes for these data do make it possible for trends discovered and presented below to be artifacts of sampling bias. However, when age was considered with cause of death, a clear pattern emerged where individuals under the age 30 years almost always died from trauma-related causes, individuals between the ages 30-49 years predominately died from drugs and alcohol and people 50 years and older typically died from heart disease.

It is clear that individuals under 30 years of age almost always suffered traumatic deaths and so the relationship between age and cause of death for this age group was not tested. A *Chi-square of independence* was used with *Fisher's Exact Test* to test whether or not age was independent of cause of death; this test only considered people in their thirties and forties and people over the age 50 years who died from drugs and alcohol or heart disease. The *Chi-square test* verified that there is a significant relationship between the type of death a person encounters and that person's age at death ($X^2=17.967$, $df=1$, $p\leq0.000$).

Figure 4.6—Causes of Death for Males.

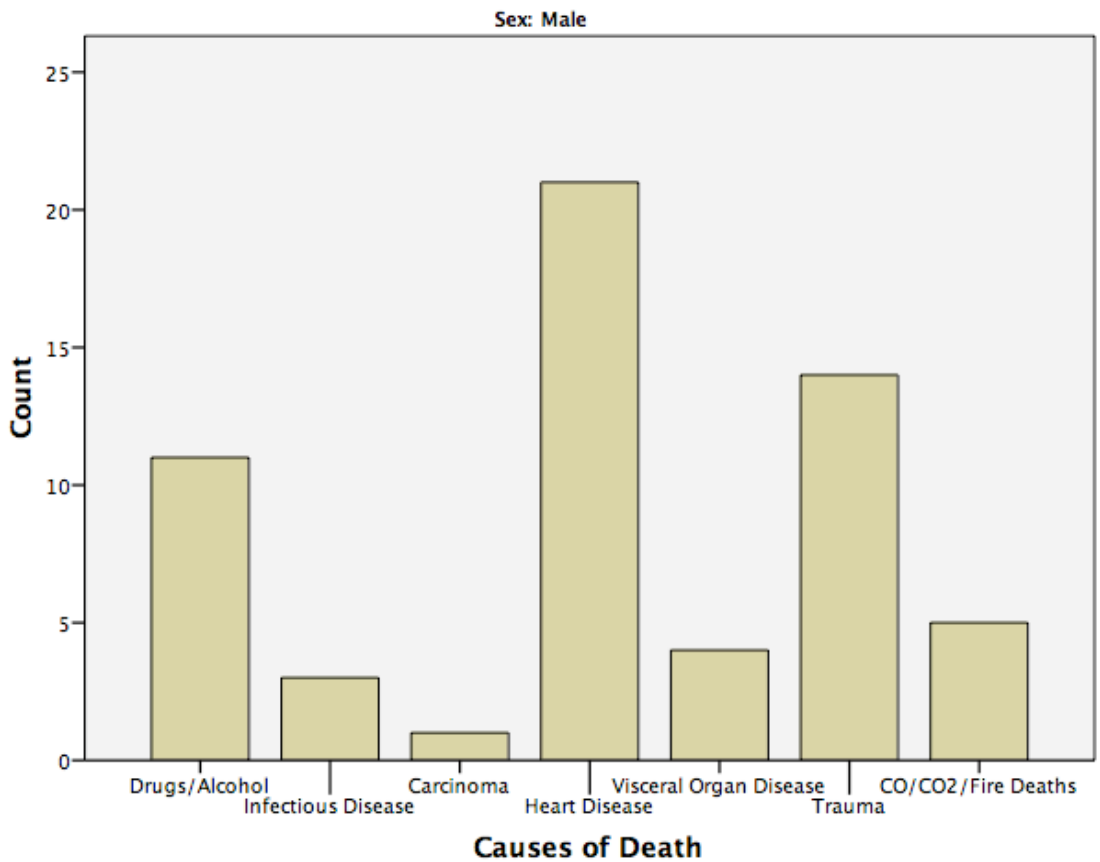


Figure 4.7—Causes of Death for Females.

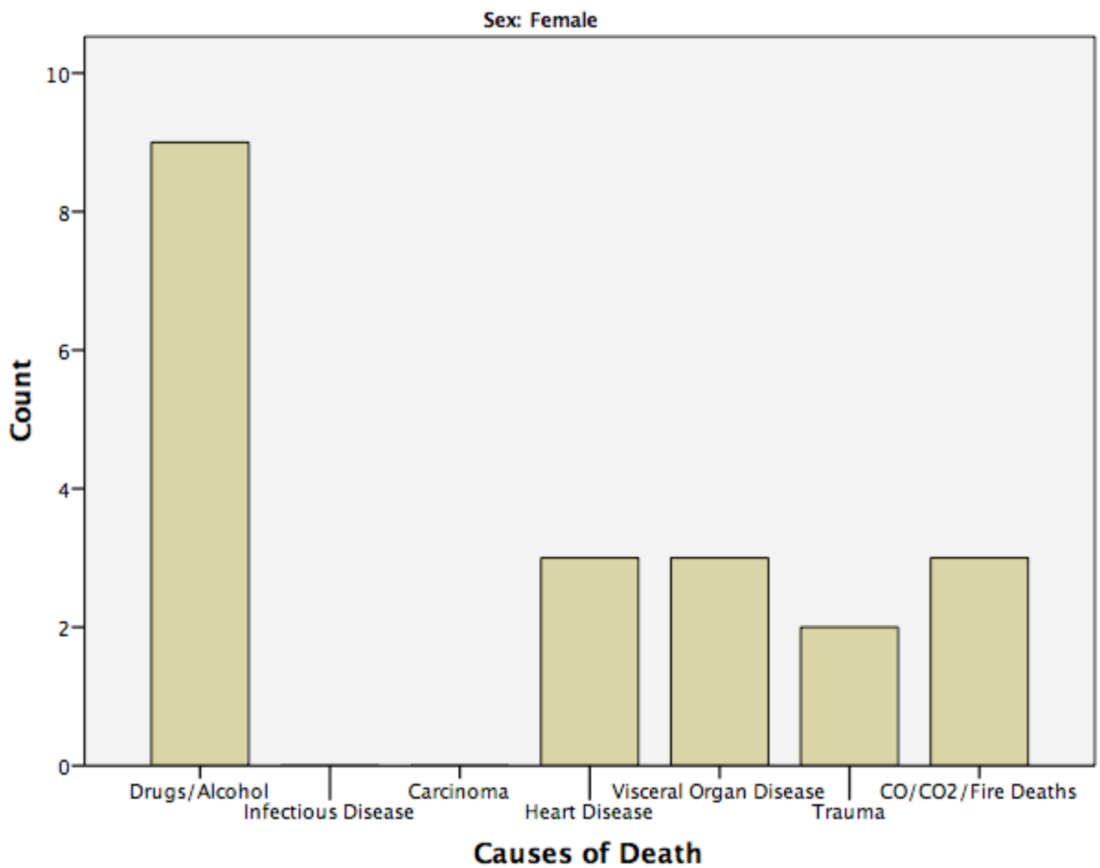


Figure 4.8—Cause of Death by Age Range.

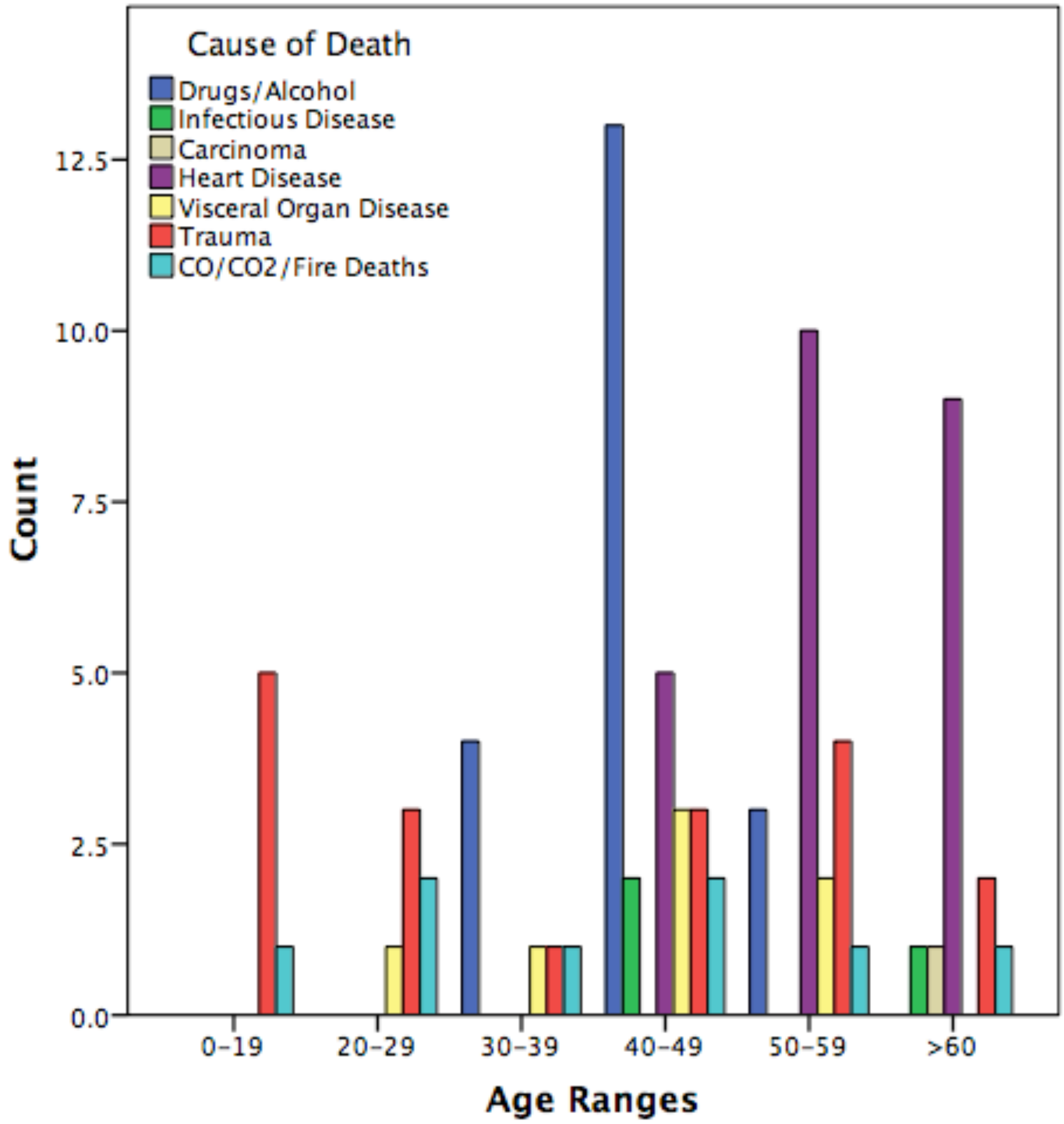


Table 4.4—Cause of Death by Age Range.

Cause		1-19	20-29	30-39	40-49	50-59	≥60
Drugs/Alcohol	n	0	0	4/81	13/81	3/81	0
	Age %	0	0	57.1	46.4	15.0	0
Infectious Disease	n	0	0	0	2/81	0	1/81
	Age %	0	0	0	7.1	0	7.1
Carcinoma	n	0	0	0	0	0	1/81
	Age %	0	0	0	0	0	7.1
Heart Disease	n	0	0	0	5/81	10/81	9/81
	Age %	0	0	0	17.9	50.0	64.3
Visceral Organ Disease	n	0	1/81	1/81	3/81	2/81	0
	Age %	0	16.7	14.3	10.7	10.0	0
Trauma	n	5/81	3/81	1/81	3/81	4/81	2/81
	Age %	83.3	50.0	14.3	10.7	20.0	14.3
CO/CO2/Fire	n	1/81	2/81	1/81	2/81	1/81	1/81
	Age %	16.7	33.3	14.3	7.1	5.0	7.1
Total	n	6/81	6/81	7/81	28/81	20/81	14/81
	Total %	7.4	7.4	8.6	34.6	24.7	17.3

Table 4.5—Descriptive Statistics for Age by Cause of Death.

Cause of Death	n	$\overline{X}$	s.d.
Drugs/Alcohol	20/81	44.35	5.451
Infectious Disease	3/81	51.33	7.767
Carcinoma	1/81	71.0	-
Heart Disease	24/81	60.17	14.107
Visceral Organ Disease	7/81	42.43	9.307
Trauma	18/81	35.11	19.745
CO/CO2/Fire Deaths	8/81	38.38	20.743

Cause and Manner of Death

Cause and manner of death are intrinsically linked, and when they were analyzed together, some trends arose. Predictably, all deaths classified as resulting from heart disease, carcinoma, and infection were natural deaths. All but one (14.3%) of the seven deaths caused by disease of the visceral organs resulted from natural deaths. The one outlier was an accidental death caused by asphyxia that resulted from gran mal seizures. Carbon monoxide, carbon dioxide or fire related deaths were distributed evenly between suicidal and accidental deaths (4/8, 50.0% each), where all suicidal deaths within this category were achieved by inhaling car exhaust fumes and all accidental deaths were the results of house fires.

Table 4.6 shows the frequency of drug or alcohol related deaths within each manner of death where drug or alcohol use was represented. The data indicated that no homicides or undetermined manners of death had drug or alcohol involvement for the decedents. However, 42.9% (6/14) of suicidal deaths had known drug or alcohol involvement. For accidental deaths, 36.8% (7/19) of the cases involved alcohol or drug use. For natural deaths, 17.1% (7/41) of the sample involved drugs or alcohol use. Suicidal and accidental deaths were lumped together and compared to natural deaths to investigate the relationship between drug and alcohol related deaths and manner of death. The *Chi-square* results indicate that there was a relationship between drug and alcohol related deaths and manners of death ($X^2=4.616, df=1, p=0.032$). The frequencies indicate that suicidal and accidental deaths are more likely to involve drugs and alcohol, despite the natural deaths that occur from long term drug or alcohol abuse.

Table 4.7 shows the frequencies of individuals who suffered traumatic deaths within each manner of death for where traumatic death was represented. There were no traumatic natural deaths and so natural deaths are not represented. All homicidal deaths (6/6) were traumatic, whereas only 28.6% (4/14) of suicidal deaths involved trauma. The relationship between traumatic deaths and homicidal or suicidal manners of death was tested with a *Chi-square of independence* and a *Fisher's exact test* ($X^2=8.571$, $df=1$, $p=0.005$). The results show that there is a relationship between manner of death and traumatic deaths, where a person who dies from homicide is much more likely to have died a traumatic death than someone who took his or her own life.

Table 4.6—Drug/Alcohol Related Deaths by Manner of Death.

	Suicide	Accident	Natural	Total
n	6/82	7/82	7/82	20/82
Drug/alcohol %	30.0	35.0	35.0	100
Manner %	42.9	36.8	36.8	24.4
Total %	7.3	8.5	8.5	24.4

Table 4.7—Traumatic Deaths by Manner of Death.

	Homicide	Suicide	Accident	Undet.	Total
n	6/82	4/82	7/82	2/82	19/82
Trauma %	31.6	21.1	36.8	10.5	100
Manner %	100	28.6	36.8	100	23.2
Total %	7.3	4.9	8.5	2.4	23.2

Demographic Profile by Context

The location where a body is discovered can provide information on the circumstances that led to one's death as well as establish the environmental parameters that set the tempo for the rate of decomposition. Figure 4.9 and Table 4.8 show the six main contexts of deposition that were identified: outdoor near-surface, outdoor subsurface, submerged, within a vehicle, indoors, and exhumed and embalmed. Of the 86 cases considered, there was one case where the context of discovery was not known. Most decedents were discovered within enclosed environments (defined here as indoor or within a vehicle; 81.1%, 69/85).

Figure 4.9—Context of Deposition.

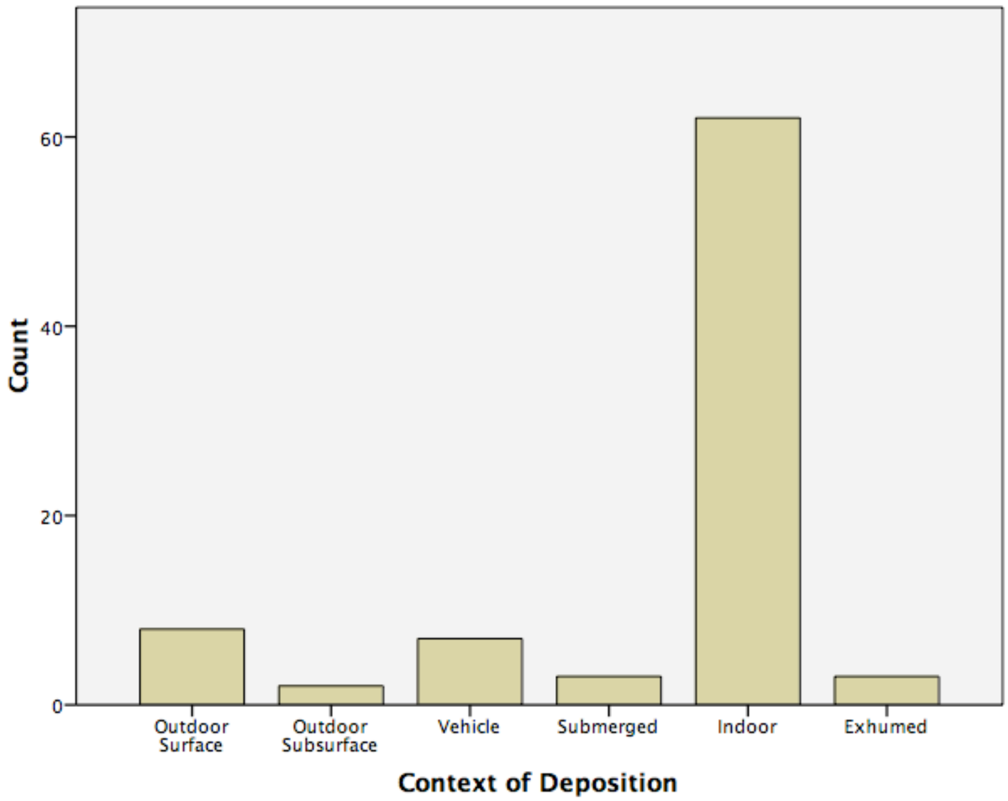


Table 4.8—Sample Sizes by Context.

Context	n	%
Outdoor Near-Surface	8/85	9.4
Outdoor Subsurface	2/85	2.4
Vehicle	7/85	8.2
Aquatic	3/85	3.5
Indoor	62/85	72.9
Exhumed	3/85	3.5

Outdoor Near-Surface Depositions

Among the eight cases recovered from an outdoor near-surface deposition, 75.5% (5/8) were men ranging in age 15-86 years. The PMI ranged from 9 days to 11 years. There are no identifiable trends in the age, sex and manner of death. Table 4.9 displays the frequencies for the manners of death experienced by victims whose bodies were discovered in outdoor near-surface environments. Most outdoor near-surface finds (62.5%, 5/8) resulted from traumatic homicides. There was also one case of an outdoor near-surface find at a private residence where the person had died from a traumatic suicide. There were two outdoor near-surface depositions that were the result of natural deaths caused by heart and visceral organ diseases, one of which occurred outside a private residence and one of which occurred within a wooded area. These frequencies indicate that a body found in an outdoor surface environment likely belongs to a victim whose death resulted from a traumatic homicide.

Table 4.9—Outdoor Near-Surface Manner of Death.

f	Homicide	Suicide	Accident	Natural	Undet.	Total
n	5	1	0	2	0	8
%	62.5	12.5	0	25.0	0	100

Outdoor Subsurface Depositions

There were only two subsurface depositions (Case 9 and Case 10). Both deaths resulted from traumatic homicides where their bodies were subsequently buried in wooded areas. The first case (Case 9) was a female baby of approximately fourteen months of age, who suffered multiple blunt force traumas to the head, neck and trunk. She was wrapped in a blanket and buried in a shallow grave, where she remained undiscovered for three months. The second case (Case 10) was an adult man who died of sharp force trauma to the trunk and blunt force trauma to the trunk and head. He was buried in a shallow grave used as a campground by transients and had a postmortem interval of "years." When considered in conjunction with the bodies discovered in outdoor surface environments, outdoor near-surface and subsurface depositions are indicative of homicide.

Aquatic Depositions

Three bodies were discovered in aquatic locations (Cases 11, 12 and 13). They all resulted from traumatic accidents involving large bodies of water. All three individuals were males whose ages ranged from 42-66 years. The PMI ranged from one day to two months and two days.

Exhumed Depositions

There were three adult males who represented the exhumed subsample (Cases 14, 15, and 16). The first case (Case 14) died from a traumatic accident. The individual had been pulled over by police but ended up in a body of water and drowned. Although the victim had been autopsied one before in Tampa, the family asked NIFS to perform a second autopsy. The second decedent (Case 15) had died within a nursing home and the family requested an exhumation and autopsy. At the time of data collection, there was no known cause or manner of death. The last case (Case 16) was found hanging in his closet by a belt ligature. His first autopsy was ruled a suicide. The family requested another autopsy by NIFS, where it was ruled that the victim died from trauma with an undetermined cause of death. The postmortem interval ranged from one to three months before exhumation.

Enclosed Depositions

The enclosed context included both vehicle depositions and bodies deposited within structures. Of the 69 enclosed cases, both men (71.0%, 49/69) and women (29.0%, 20/69) were represented and ranged in age from two months to 90 years. Figures 4.10 and 4.11 show the age distributions for males and females, respectively. Table 4.10 shows the descriptive statistics for males' and females' ages at death, which was known for 97.1% (67/69) of the enclosed sample. For vehicle depositions, there were three males and three females whose ages ranged from 18 to 50 years. Their postmortem intervals spanned from one day to one week. For indoor, there were forty-five males and seventeen females whose ages ranged from 2 months to 90 years, although only 2 victims were subadults. The indoor cases' postmortem intervals spanned from one to 66 days.

Figure 4.10—Enclosed Deposition Age Distribution for Males.

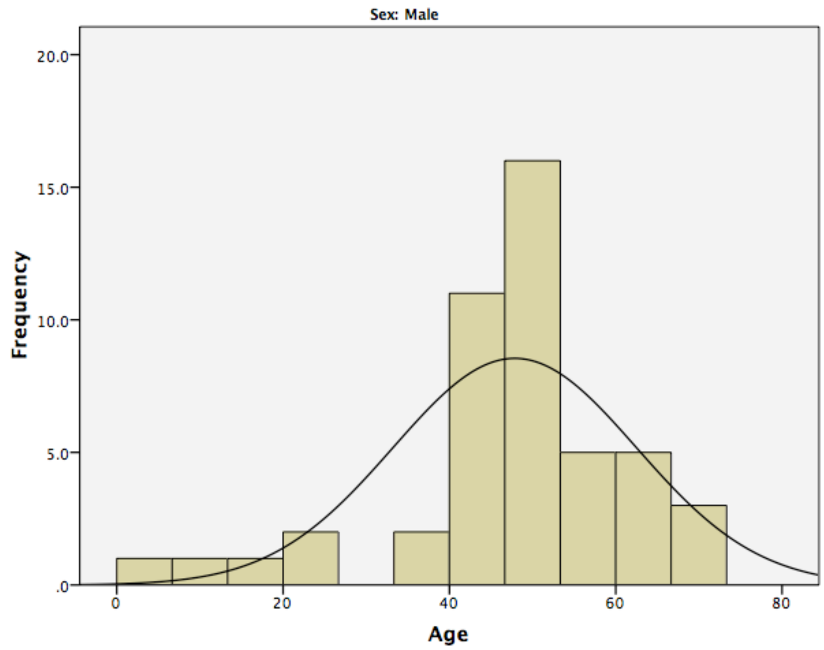


Figure 4.11—Enclosed Deposition Age Distribution for Females.

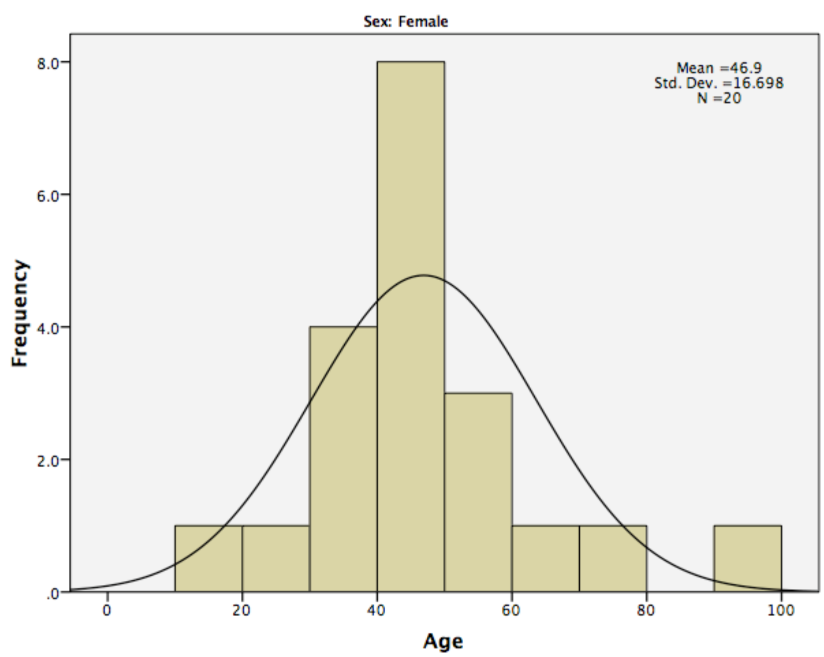


Table 4.10—Enclosed Deposition Descriptive Statistics for Age at Death by Sex.

Descriptive Statistics	Males	Females
n	47	20
$\overline{X}$	47.85	46.90
s.d.	14.624	16.698

Table 4.11—Enclosed Deposition Manner of Death.

Context		Homicide	Suicide	Accident	Natural	Undet.	Total
Vehicle	%	0	71.4 (5/7)	14.3 (1/7)	14.3 (1/7)	0	7/7
Building	%	3.2 (2/62)	12.9 (8/62)	22.6 (14/62)	59.7 (37/62)	1.6 (1/62)	62/62
Total	%	2.9 (2/69)	18.8 (13/69)	21.7 (15/69)	55.1 (38/69)	1.4 (1/69)	69/69

Cause and Manner of Death

Table 4.11 shows the frequencies of manners of death within vehicles and buildings. Vehicle depositions were mostly results of suicides from inhalation of car exhaust fumes (71.4%, 5/7). Vehicle suicides occurred in a range of places, including one person who chose a place along a roadside (16.7% of vehicle depositions), one person who opted for a parking garage, two who chose private residences (33.3% of vehicle depositions), and two who decided upon wooded areas (33.3%). One person (14.3%) also died within their vehicle in a parking garage from bronchopneumonia and one person (14.3%) died in their vehicle from severe trauma and subsequent cold exposure after her car ran off the road and into a ravine where she remained undiscovered for approximately eight days.

For all enclosed cases where it was known, police and family were most often the ones to discover the remains (26.4%, 14/53 for each). More than half (59.7%, 37/62) of the indoor finds resulted from deaths by natural causes. All indoor depositions were discovered within private residences (96.8%, 60/62) or hotel rooms (3.2%, 2/62). Of the cases where it was known, the most common places in the home for people to die were bedrooms (38.6%, 22/57) and living rooms (33.3%, 19/57) followed by garages (12.3%, 7/57) and bathrooms (10.5%, 6/57).

Case 17 and 18: The two cases discovered in hotel rooms were labeled Case 17 and 18. Both deaths resulted from drug overdoses, although the manner varied. Case 17 was a man who had driven from Florida to Nebraska to tell his estranged wife that he had cancer. After she rebuked him, he committed suicide by overdosing in his hotel room.

Case 18 was of a man who had a history of drug addiction and depression. He died of an accidental drug overdose in his hotel room.

Case 19 and 20: The two subadults who died within enclosed environments were removed from the decomposition analysis on the basis that their body sizes could lead to outlying rates of decay. Both children only had a postmortem interval of less than one day. Case 19 was that of a seven-year-old male who died from a house fire that started while the family was sleeping. He suffered from thermal burns as well as smoke and soot inhalation. Case 20 was that of a two-month-old baby who suffocated at home and was discovered under a blanket in his crib. The mother's boyfriend said that he found the baby that way, but it was marked as a suspicious death by police investigators. The manner of death was undetermined.

Differences in PMI among Manners of Death

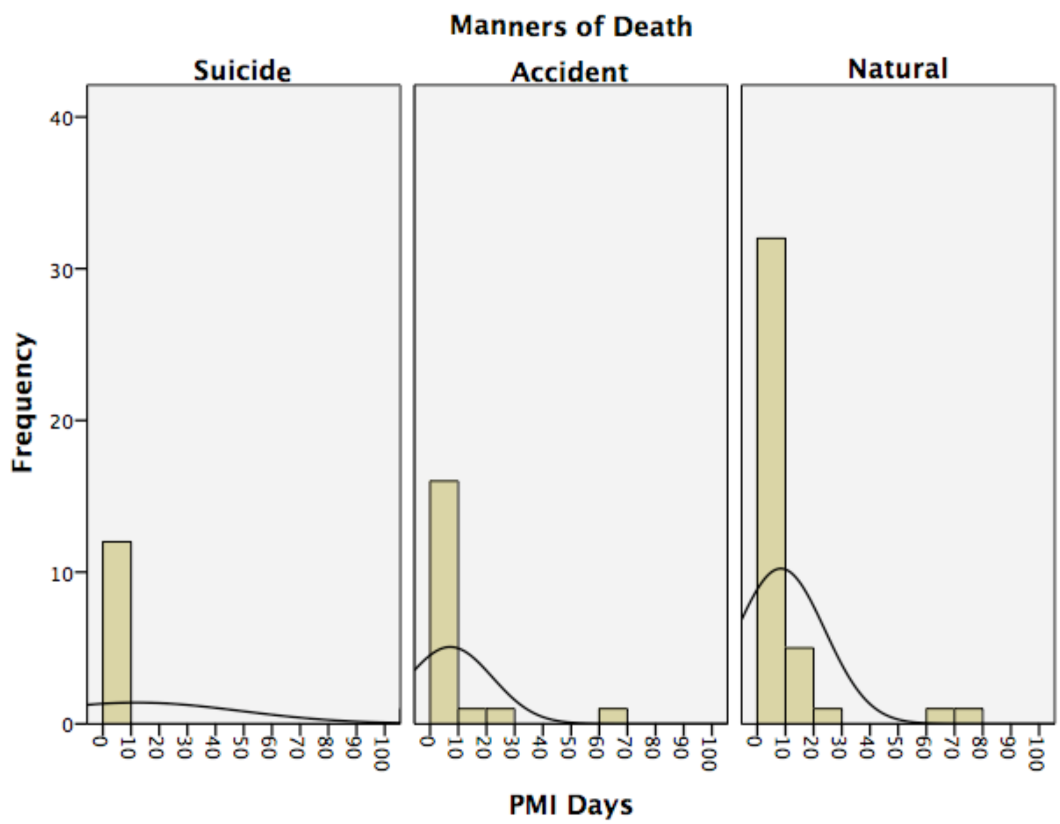
It was of interest to determine whether the length of time bodies remained undiscovered differed among manners of death. Table 4.12 shows the descriptive statistics for PMI by manners of death. Figure 4.12 shows the distribution for suicides, accidents and natural deaths. Figure 4.13 shows the distribution for homicides. While only 55.56% (5/9) of homicides were represented, this category contained the longest postmortem intervals. Differences in PMI among suicides, accidents and natural deaths were tested with a *Kruskal-Wallis test*. It was found that there was no difference in the PMI among suicides, accidents and natural deaths ($X^2=2.148, df=2, p\leq 0.342$). The PMI for homicides could not be tested due to the small sample size (5/85). However, homicides were characterized by extended postmortem intervals. Most homicides (7/9; 77.78%) were located in outdoor near-surface or subsurface environments, which was indicative of efforts to conceal the events and the remains.

Table 4.12—Description of PMI by Manner of Death.

Manner of Death	n	PMI Range	*M*	$\overline{X}$	s.d.
Homicide	5/85	9 – 4026	257.00	1097.80	1692.51
Suicide	13/85	1 – 135	1.00	11.96	36.98
Accident	19/85	1 – 63	1.00	7.16	14.95
Natural	40/85	1 – 76	3.00	8.36	15.59
Undet.	2/85	1 – 83	42.00	42.00	57.98

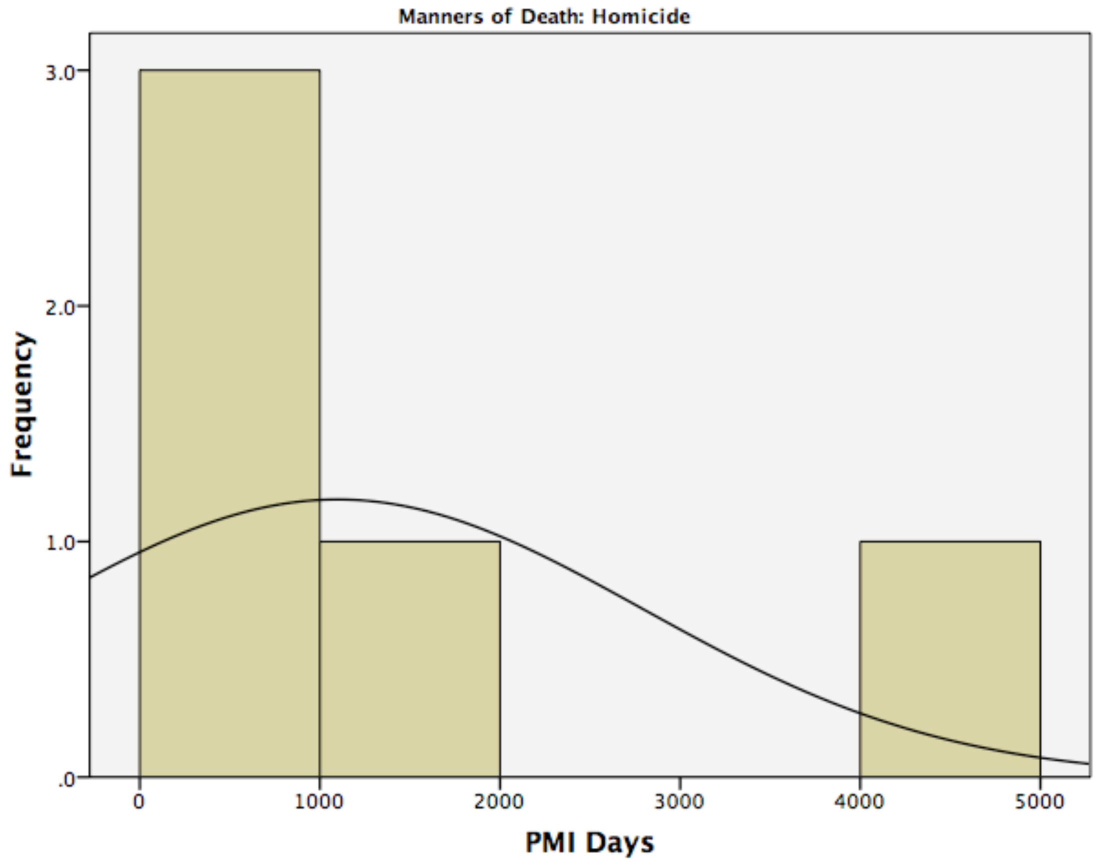
* The sample size is 85 because there is one case missing information on the MOD.

Figure 4.12—PMI Distributions for Suicides, Accidents and Natural Manners of Death.



* Homicides were depicted separately due to the extended postmortem intervals represented. The two undetermined deaths were not depicted.

Figure 4.13—PMI Distribution for Homicides.



* Homicides were depicted separately due to the extended postmortem intervals represented.

Taphonomy, the Postmortem Interval and ADD

Description of PMI and ADD for All Cases

The postmortem interval and accumulated degree days were the dependent variables targeted for prediction. Figure 4.14 displays the distribution of the PMI (in days) for the entire sample. Figure 4.15 shows the distribution of ADD for the entire sample (in Celsius). The postmortem interval is known for eighty individuals and ranges from one hour to 11 years, although most individuals have a PMI of less than one year ($\overline{X}$=78.22, *M*=3.00, *s.d.*=464.44 days). The ADD are known for seventy six cases and range from 0.0-2536.11 ADD ($\overline{X}$=125.46, *M*=30.84, *s.d.*=388.23 ADD). Most cases belong to the lower spectrum for ADD and PMI, but there are a few outliers.

As previously mentioned in the protocol description, investigators recorded each cadaver's level of decomposition based on the description of Bass' stages that best fit the state of the remains in question (Table 2.2). Figure 4.16 shows the mean PMI days and frequencies for each stage of decomposition. For example, this table shows that among the 28 bloated cases, the mean PMI was 14 days. Table 4.13 shows the frequencies for each stage of decomposition for the entire sample. In accordance with Bass' stages, most of the cases were either fresh or bloated. Table 4.14 shows the range of PMI in days for each stage of decay and Table 4.15 shows the range of ADD for each stage of decay.

The pace of decompositional change is determined primarily by the environmental context, and so each environmental setting was analyzed separately. Table 4.16 shows the frequencies of decomposition stages within each environmental context. All six cases that were more than 25.0% skeletonized were either outdoor near-surface or shallow subsurface finds. As a result of the sample composition, skeletonization was not well represented in any contexts other than outdoors. Table 4.17 shows the ranges in PMI days for each stage of decay within each context. These ranges were a function of small sample sizes and also variability within each context.

Reliability of Bass' Model for All Contexts Combined

In Bass' decomposition scale, each stage of decomposition is associated with a time range. Figure 4.17 and Table 4.18 show the frequencies of individuals within each stage of decay for each of Bass' time ranges. The frequencies show some deviation from what Bass' model would predict, particularly in the first week to first month time frame and afterwards. Overall, the trends in the data seem to fit fairly well with Bass' predictive model. A *Spearman's correlation* was used to test how well Bass' stages of decay fit with the PMI time frames and yielded the following results: $r=0.801,\ n=81,\ p\leq 0.000$. These results indicate that the stages of decay account for a significant portion of the variation in PMI time ranges, and overall his model is a good fit, despite the variable contexts of deposition. However, the literature provides substantial support for environmental variability. Therefore, despite these results, each context was analyzed separately.

Figure 4.14—PMI (Days) Distribution.

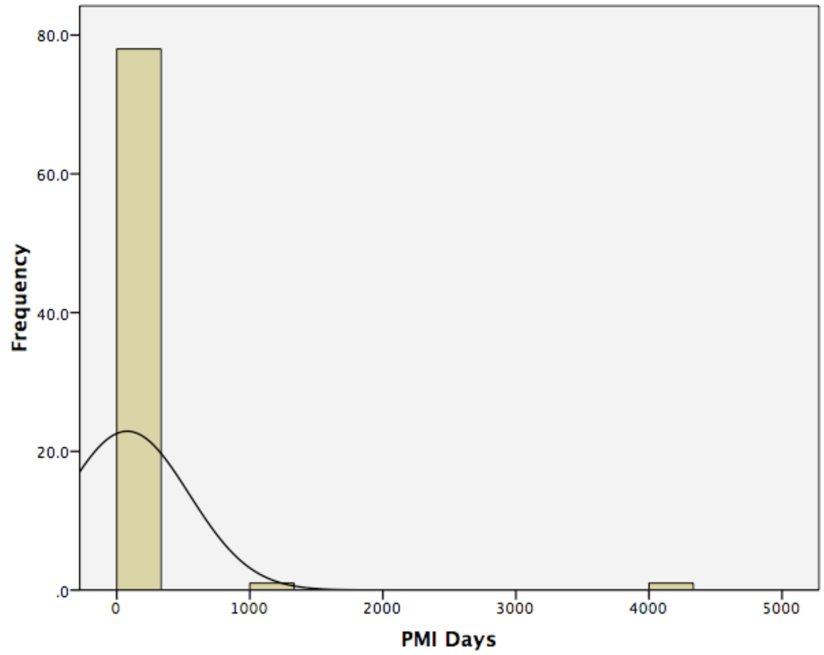


Figure 4.15—ADD (˚C) Distribution.

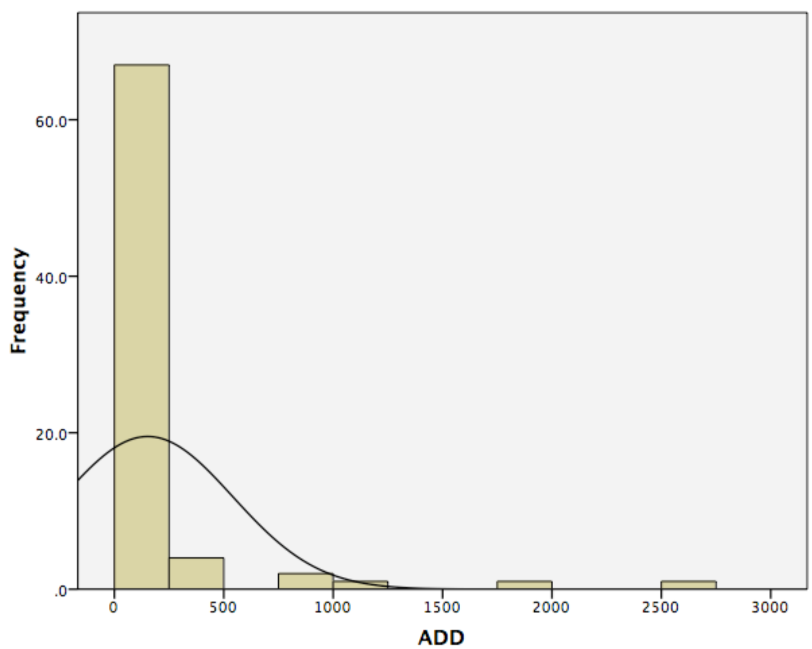


Figure 4.16—Mean PMI Days and Frequencies for Bass' Decomposition Stages.

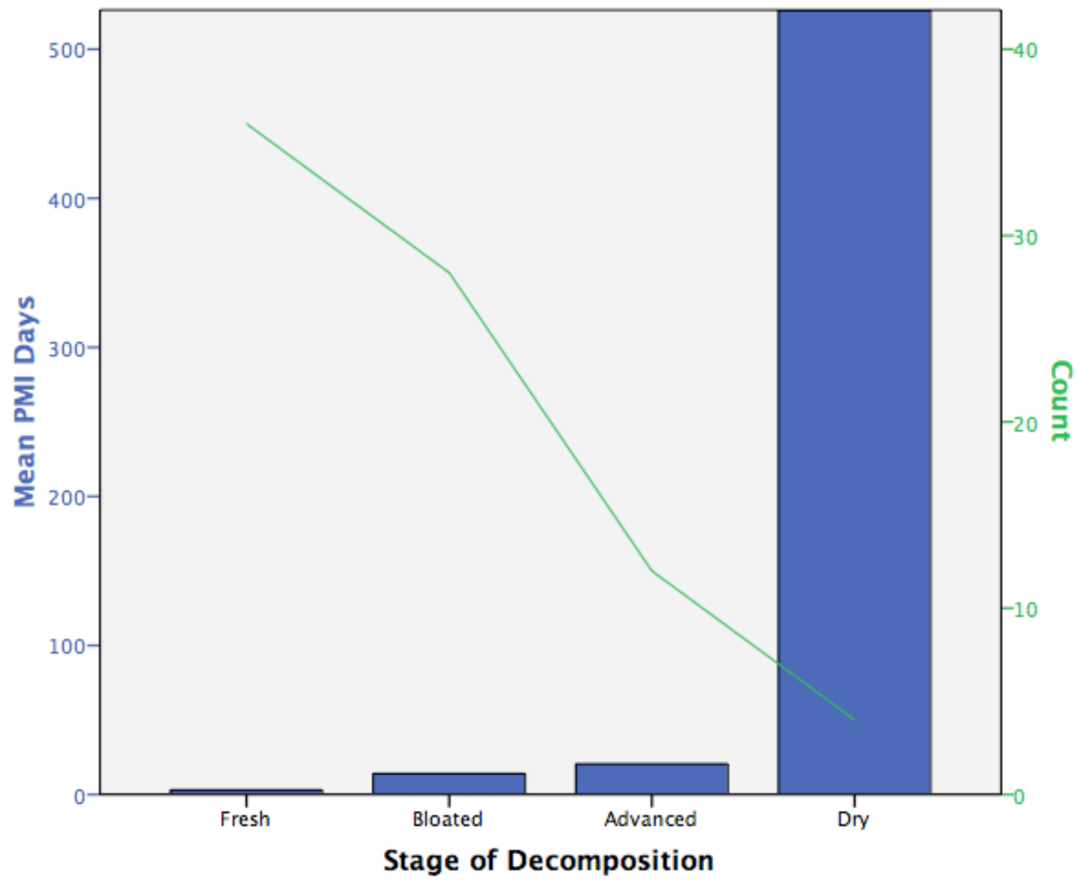


Table 4.13—Case Frequencies by Stage of Decomposition.

Stage of Decay	n	%
Fresh	37/86	43.0
Bloated	32/86	37.2
Advanced	12/86	14.0
Dry	5/86	5.8

Table 4.14—PMI Day Range by Stage of Decomposition.

Stage of Decay	PMI Days
Fresh	1 – 59
Bloated	1 – 102
Advanced	2 – 76
Dry	135 – 4,026

Table 4.15—ADD Range by Stage of Decomposition.

Stage of Decay	ADD (˚C)
Fresh	0 – 818
Bloated	0 – 342
Advanced	9 – 1,144
Dry	1,800 – 2,168

Table 4.16—Decomposition Stage by Environmental Contexts.

Bass' Decay Stages	Context of Deposition						
	Outdoor Near-Surface	Sub-Surface	Vehicle	Submerged	Indoor	Exhumed	Total
Fresh	0	0	4.7% (4/85)	1.2% (1/85)	36.5% (31/85)	1.2% (1/85)	37
Bloated	1.2% (1/85)	1.2% (1/85)	0	2.4% (2/85)	29.4% (25/85)	2.4% (2/85)	31
Advanced	3.5% (3/85)	0	3.5% (3/85)	0	7.1% (6/85)	0	12
Dry	4.7% (4/85)	1.2% (1/85)	0	0	0	0	5
Total	9.4% (8/85)	2.4% (2/85)	8.2% (7/85)	3.5% (3/85)	72.9% (62/85)	3.5% (3/85)	85

Table 4.17- PMI Day Ranges for Decay Stages by Context.

Bass' Decay Stages	Context of Deposition					
	Outdoor Near-Surface	Sub-Surface	Vehicle	Submerged	Indoor	Exhumed
Fresh	-	-	1-7.5	1	1-4	59
Bloated	-	-	-	2-63	1-17	27-83
Advanced	9-76	102	2-3	-	8-66	-
Dry	135-4,026	-	-	-	-	-

Figure 4.17—Bass' Time Ranges and Decomposition Stages.

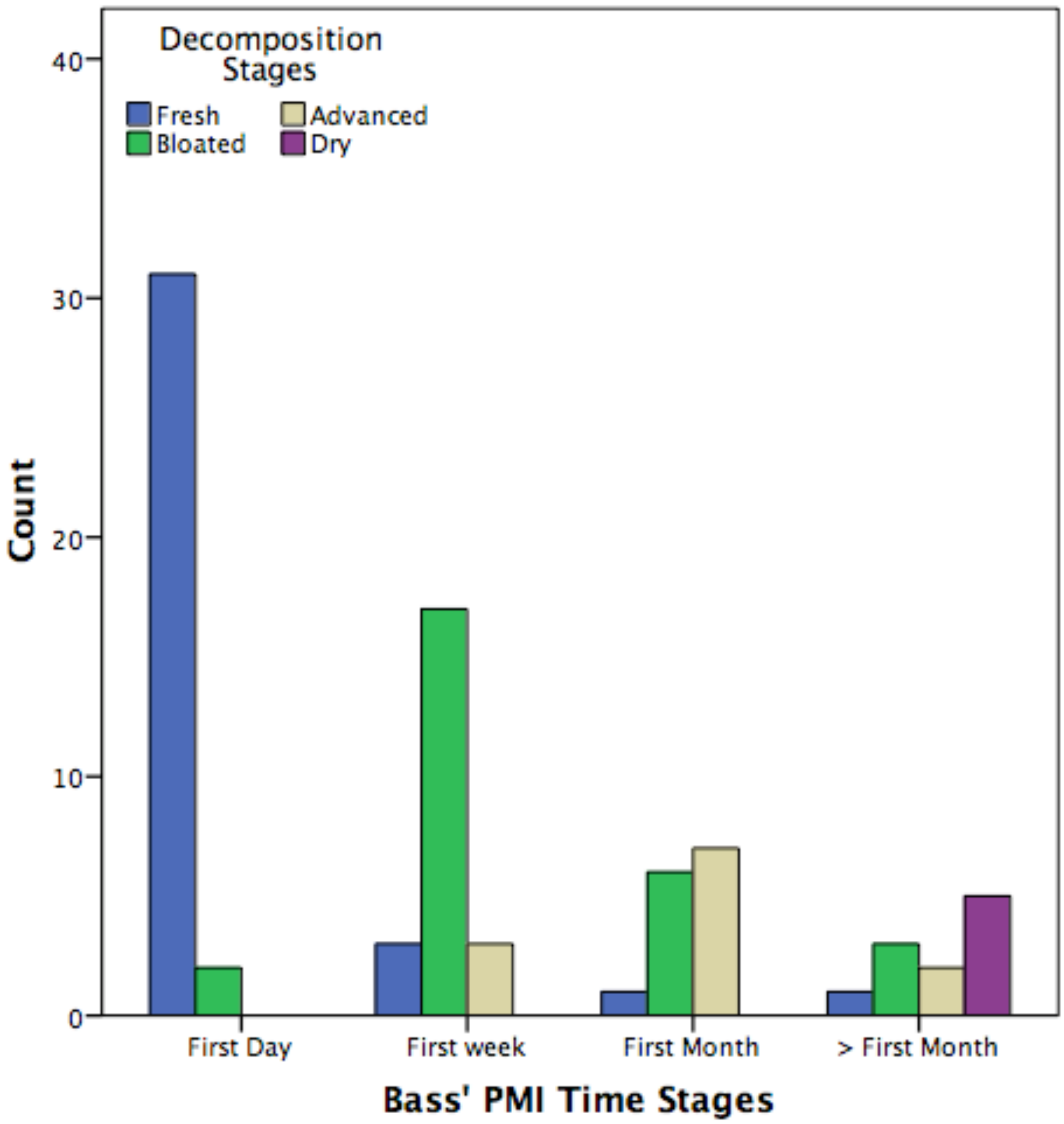


Table 4.18—Stage of Decay by Time Range.

Time Range	*f*	Fresh	Bloated	Advanced	Dry	Total
1st Day	n	31/81	2/81	0	0	33/81
	Time Range %	93.9	6.1	0	0	100
	Total %	38.3	2.5	0	0	40.7
1st Week	n	3/81	17/81	3/81	0	23/81
	Time Range %	13.0	73.9	13.0	0	100
	Total %	3.7	21.0	3.7	0	28.4
1st Month	n	1/81	6/81	7/81	0	14/81
	Time Range %	7.1	42.9	50.0	0	100
	Total %	1.2	7.4	8.6	0	17.3
>1st Month	n	1/81	3/81	2/81	5/81	11/81
	Time Range %	9.1	27.3	18.2	45.5	100
	Total %	1.2	3.7	2.5	6.2	13.6
Total	n	36/81	28/81	12/81	5/81	81
	Total %	44.4	34.6	14.8	6.2	100

Outdoor Near-Surface Depositions

Bass' Decomposition Stage, ADD and PMI

Figure 4.18 displays the frequencies for each stage of decomposition the bodies were found in. Of the eight outdoor near-surface finds, there were no fresh cases represented and the majority of decedents were in the dry phase of decomposition when discovered. The only decedent who was discovered in the bloated stage did not have associated information on the PMI, and unfortunately could not be considered for this portion of the analysis.

Table 4.19 shows the PMI in days and the ADD in ˚C for when it was known. For the outdoor near-surface subset, the postmortem interval ranged from 9 days to 11 years, although most PMI were longer than one month ($\overline{X}$=801.29, *M*=135, *s.d.*=1472.16 days). For cases 1, 7 and 8, ADD were not calculable. For the cases where it was known, ADD ranged from 199 – 2536 ADD ($\overline{X}$=1177.67, *M*=1144.44, *s.d.*=1016.16 ADD).

Figure 4.19 and Table 4.20 represent the frequency of cadavers that were discovered within Bass' time ranges of the first week to first month and after the first month of deposition and their accompanied state of decomposition. Bass' (1997) model predicts that all dry cases will have undergone a postmortem interval longer than one month, and this prediction is consistent with the data, where all dry cases' PMIs ranged from 4 months and 11 days to 11 years. According to Bass' (1997) model, bodies should reach an advanced stage of decomposition within one week and one month of time. The data show that 2/3 (66.7%) advanced decomposition cases did decompose within the above stated time frame (range=9-11 days) and one advanced case (33.3%) had a longer

PMI of 2.5 months. The latter postmortem interval was that of a body that had decomposed during the winter months and the cool temperatures might best explain this extended PMI. Overall, these data fit very well with Bass' model.

Figure 4.18—Outdoor Near-Surface Decomposition Stages (n=8).

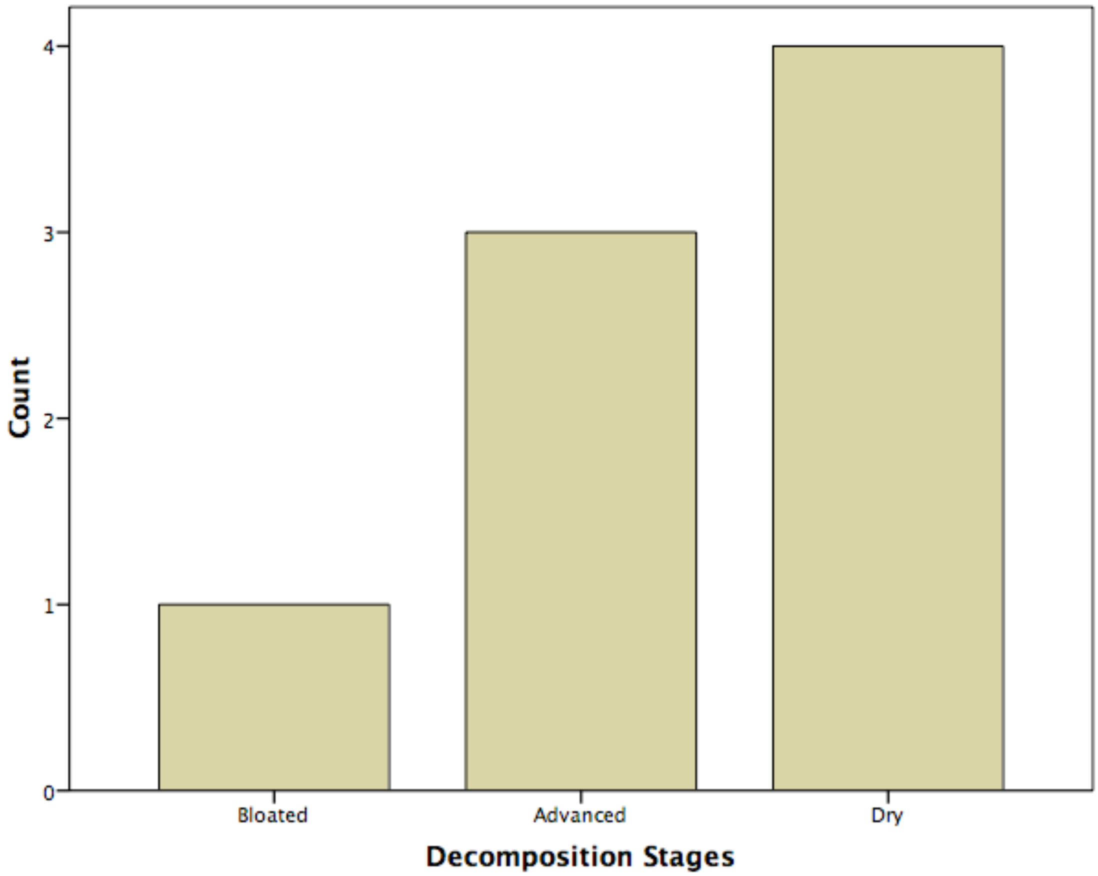


Table 4.19—Outdoor Near-Surface PMI Days for Each Case.

Case #	PMI Days	ADD	Stage of Decay
Case 1	-	-	Bloated
Case 2	9	199	Advanced
Case 3	11	209	Advanced
Case 4	76	1,144	Advanced
Case 5	135	88.16	Dry
Case 6	257	1,800	Dry
Case 7	1,095 (≈3 years)	-	Dry
Case 8	4,026 (≈11 years)	-	Dry

Figure 4.19—Outdoor Near-Surface Decay and PMI Stages (n=7).

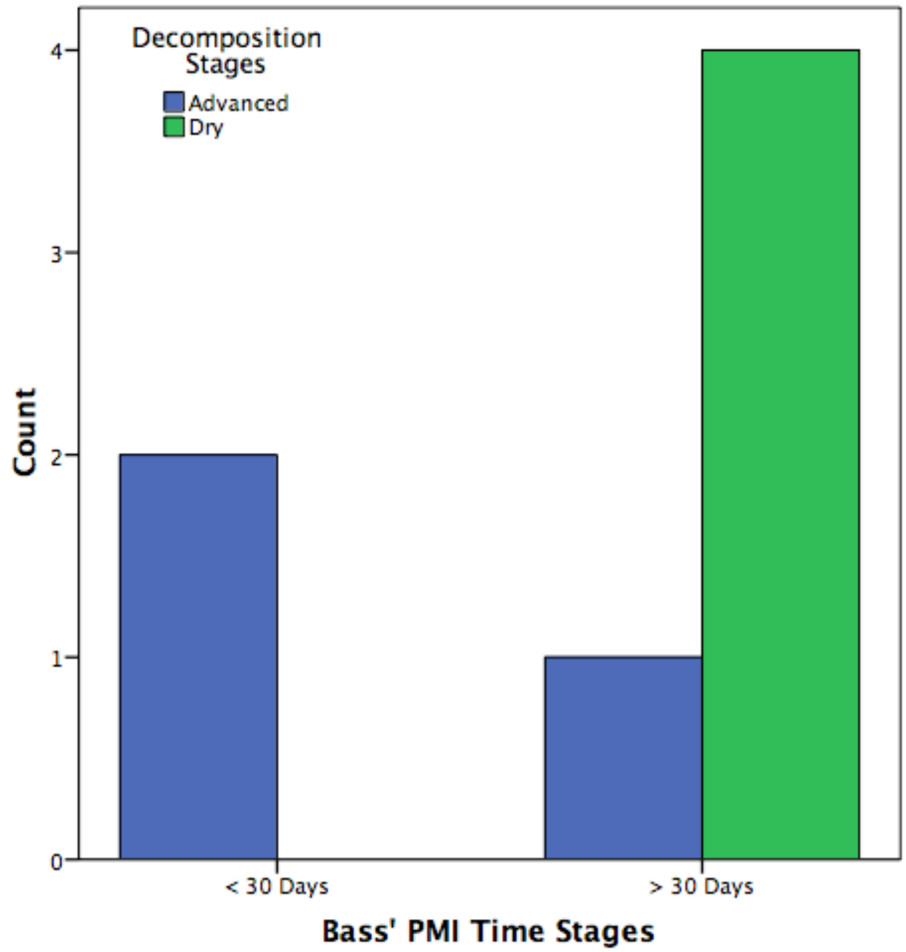


Table 4.20— Percentage of Near-Surface Decay Stages that Transpired within Predicted Time Ranges (n=7).

PMI Range	Advanced	Dry	Total
First Month	66.7 (2/3)	0	28.6 (2/7)
> First Month	33.3 (1/3)	100 (4)	71.4 (5/7)
Total	100 (3/3)	100 (4)	100 (7)

Anthropophagy

The prevalence of anthropophagy was investigated to see if the Nebraska data were consistent with what has been identified in Tennessee. It was found that 87.5% (7/8) cases exhibited some type of evidence for necrophagous activity. Table 4.21 shows all animals and insects identified as having fed on the remains. The bloated case had no evidence of necrophagy. Three (37.5%) cases displayed evidence that more than one type of organism had been involved in soft tissue removal and all 3 of these cases were in the dry stage of decomposition. Case 8 was associated with the remains of blow flies (Phormia *regina*) and Coleopteras, and exhibited disarticulation that was consistent with canine scavenging. Case 5 showed evidence of both fly and canine scavenging. Canids, rodents, beetles and flies had all been involved in soft tissue destruction of Case 6.

Intrinsic Effects and PMI Time Ranges

Intrinsic effects in conjunction with PMI were identified for this sample. Table 4.22 presents a list of taphonomic effects that were represented in the sample and their associated time ranges. Sample sizes varied for each taphonomic effect in every time range. The variation in sample sizes reflects cases where the information was unknown, due to the quality of the records from which the data were collected. Thus, the variable sample sizes reflect unknown cases. For example, for when it was known, skin slippage was identified in all cases that occurred within the first week to first month time range. Skin slippage was still present on 20.0% (1/5) of the cases that had a PMI longer than one month. Most effects were found to occur within the first month.

Figures 4.20 shows the percentage of how often each effect was documented within each time range. Skin slippage, marbling, mummified skin, odor, blood clots, liquefied brain tissue, and examinable organs were identified predominately on remains that had a PMI range within the first month. Soil stain was the only taphonomic effect that is unique to postmortem intervals longer than one month within this sample.

Table 4.23 represents the degree of skeletonization for bodies that had a postmortem interval that fell within one month, one year or years. The bloated body (Case 1) had no skeletonization and information on skeletonization was unknown for Case 3. It was found that only one case of skeletonization was in the first month of decomposition and this body showed approximately 50.0% skeletonization. All cases within the first year of decomposition (3/7) showed some degree of skeletonization, and all cases that had a PMI longer than one year (2/7) were fully skeletonized.

Table 4.21—Outdoor Near-Surface Prevalence of Anthropophagy.

Anthropophagy	Bloated	Advanced	Dry	Total
Canine	0	0	75.0% (3/4)*	37.5% (3/8)**
Rodent	0	0	25.0% (1/4)	12.5% (1/8)
Fly	0	100% (3)	75.0% (3/4)	75.0% (6/8)
Beetle	0	33.3% (1/3)*	0	12.5% (1/8)

* Denominator represents the sample size for a given stage of decay.
** Denominator represents the total sample size.

Table 4.22—Outdoor Near-Surface Taphonomic Effects by Time Range.

Taphonomic Effect	First Month	> First Month	Total
	PMI %	PMI %	Total %
Skin Slippage	100 (2)*	20.0 (1/5)*	42.9 (3/7)*
Marbling	100 (1)	0	16.7 (1/6)
Green Discoloration	20.0 (1/5)	0	20.0 (1/5)
Mummified Skin	100 (2)	60.0 (3/5)	71.4 (5/7)
Decomposition Odor	100 (2)	50.0 (2/4)	66.7 (4/6)
Blood Clot	100 (1)	0	16.7 (1/6)
Soil Stain	0	100 (3)	75.0 (3/4)
Brain Liquefaction	100 (2)	100 (5)	100 (7)
Examinable Organs	100 (2)	0	28.6 (2/7)

* The total outdoor near-surface sample for where the PMI was known equaled 7. However, sample sizes varied for each taphonomic effect by time range. The sample size variability reflects the differentiation between cases that were present/absent versus unknown. Therefore, what looks like missing cases represents where information was unknown.

Figure 4.20—Outdoor Near-Surface Taphonomic Effects by Time Range.

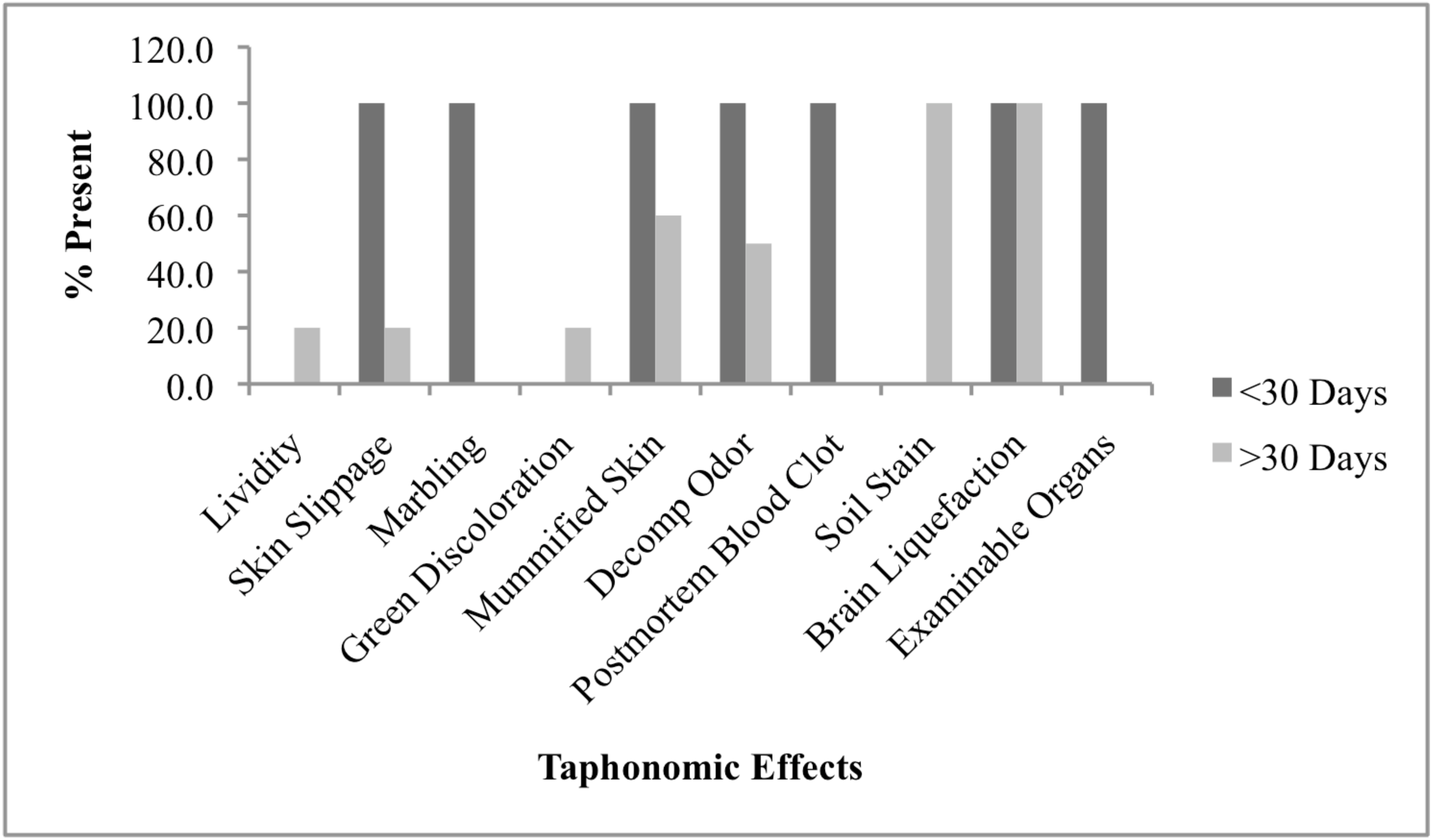


Table 4.23—Outdoor Near-Surface Skeletonization by PMI (n=6).

Skeletonization	First Month	First Year	Years	Total %
	PMI %	PMI %	PMI %	
≈25.0%	0*	33.3 (1/3)*	0*	16.7 (1/6)**
≈50.0%	100 (1)	0	0	16.7 (1/6)
≈75.0%	0	33.3 (1/3)	0	16.7 (1/6)
≈100%	0	33.3 (1/3)	100 (2)	50.0 (3/6)
Total	100 (1)	100 (3)	100 (2)	100 (6)

* Denominator represents the sample size for a given time range.
** Denominator represents the total sample size.

Outdoor Subsurface Depositions

Taphonomic Processes and Effects

There were two subsurface depositions, both of which were located in shallow graves. One of the depositions was that of a child whose body was in the bloated stage of decay and had decomposed for approximately three months (Case 9). The other was an adult male whose body was completely skeletonized and had an estimated postmortem interval of multiple years (Case 10). The first case (Case 9) possessed several variables that were compatible with a decelerated rate of decay, while the second case (Case 10) showed evidence of extrinsic variables that were consistent with a surface burial.

The first case (Case 9) was a fourteen-month-old female subadult. After the juvenile was murdered, she was wrapped in a blanket "container" and buried in a shallow grave. The decedent had a postmortem interval of three months. Additionally, the postmortem interval spanned across January to March, and the accumulated degree days remained relatively low (ADD=342˚ C). This body was in a bloated state of decomposition, exhibiting green discoloration, bloating of some portions of the body, adipocere development on the face, trunk and extremities, mold growth on the face and skin slippage around the abdomen, perineum and feet.

The second case (Case 10) was found in the dry stage of decomposition and the postmortem interval was estimated as years, although the number of years was not known at the time of data collection. He was discovered in a shallow clandestine burial in a wooded area that transients often used as a campground. While this deposition was categorized as subsurface, most of the body was only covered by leaf litter and seven inches of soil or less. The top of the skull was only about an inch below the soil surface and the right arm was partially visible above the soil. The deepest portion of the grave excavated was approximately nine inches above the body. Roots had grown through the soil in the grave.

This case (Case 10) was completely skeletonized upon discovery, with only a small segment of brain tissue within the cranium, a piece of fat on one scapula and bits of soft tissue within the soil. The bones exhibited staining of the same hue as the leaves surrounding it. Additionally, the femurs were bleached white and one ischium and pubis exhibited green discolorations. Roots had grown back through the grave area. There was evidence of fly colonization in the form of pupae casings that suggested the flies had undergone the total process of development. Entomological data enabled the estimation of the time of death as having occurred between August first and the first frost of an undetermined year. Additionally, there was evidence of substantial canid scavenging; the right forearm was missing and the distal ends of both femurs displayed carnivore tooth impressions.

<u>Aquatic Depositions</u>

Taphonomic Processes and Effects

Table 4.24 shows the stages of decomposition represented within Bass' postmortem interval time ranges. The first case (Case 11) was discovered in a fresh state and the other two cases (Case 12 and 13; 66.7%) were bloated. Both bloated cases had decomposed during the warm summer months. None of the cases had evidence of necrophagous activity.

The first case (Case 11) had a short estimated postmortem interval of one day and fit well within the fresh stage of decomposition. The only decompositional effects noted on Case 11 were rigor mortis, purple lividity and swelling around the eyes, which was interpreted as early signs of decomposition gases accumulating within the facial tissues.

The second case (Case 12) was in a bloated state of decomposition. This case was estimated to have decomposed for two days and was consistent with the bloat time range in Bass' (1997) predictive model. When discovered, this cadaver had decompositional gases frothing around the body's eyes, mouth and navel region. Both of his hands were macerated and the entire body possessed skin slippage. His body was bloated and discolored and the veins were marbled. The decedent's brain was moderately liquefied when it was removed from the body during autopsy.

The third case (Case 13) had an estimated PMI of two months and two days and was also in a bloated state of decay. The hallmarks of the bloat stage were all present, including the odor of decay, skin slippage, bloating and green discoloration.

Table 4.24—Aquatic Deposition Stage of Decomposition by PMI Time Range (n=3).

	Fresh	Bloated	Total
	% Stage	% Stage	% Total
First Day	100 (1)	0	33.3 (1/3)
First Week	0	50.0 (1/2)	33.3 (1/3)
First Month	0	50.0 (1/2)	33.3 (1/3)
Total	100	100 (2)	100 (3)

Enclosed Environments

Likelihood of Decomposition Before Discovery between Seasons

To determine the likelihood of decomposition before discovery in the spring and summer versus the fall and winter, the data were organized into the cross-tabulation shown below (Table. 4.25). The *odds ratio* was calculated as follows: (*18x20)/(15/16)=1.5*. Thus, a body is 1.5 times more likely to decompose before discovery in the spring or summer than in the fall or winter. In contrast, a body is 0.67 times less likely to decompose before discovery in the fall or winter than in the spring or summer.

Table 4.25—Enclosed Deposition Presence of Decay by Seasonality.

Stage of Decay	Spring/Summer	Fall/Winter	Total
Fresh	(a) 15	(b) 20	35
Bloated/Advanced	(c) 18	(d) 16	34
Total	33	36	69

Relationship between PMI, ADD and Stage of Decay

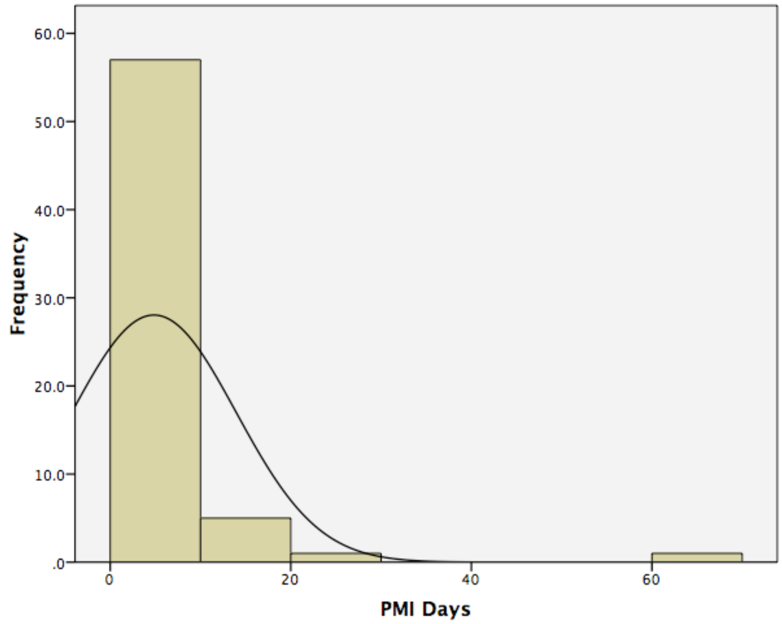
Cases 19 and 20 were removed on account of their small body sizes. Figure 4.21 shows the enclosed sample's distribution of PMI days and Figure 4.22 shows the distribution for ADD. The postmortem interval was known for 64 cases and ranged from one to 66 days, with a *mean PMI=4.84 days, s.d.=9.1037, M=2.0 days*. Figure 4.23 shows the PMI day distribution for each stage of decomposition. Table 4.26 shows the descriptive statistics for the postmortem intervals associated with each stage of decomposition. A *Spearman's Correlation test* showed that there was a significant relationship between PMI and decomposition ($r=0.772, p\leq0.000, n=64$). The ADD were known for 64 cases and ranged from 0 – 786 ADD, with a *mean ADD=67.43, s.d.=120.275, M=24.44 ADD.* Figure 4.24 shows the ADD distribution for each stage of decay. Table 4.27 shows the ADD descriptive statistics for each stage of decomposition. A *Spearman's Correlation test* showed that there was a significant relationship between ADD and stages of decomposition ($r=0.585, p\leq0.000, n=64$).

Reliability of Bass' Decomposition Model

The investigation of decompositional phases for the enclosed cases revealed that there were 49.3% (33/67) fresh, 37.3% (25/67) bloated, and 13.4% (9/67) advanced. The dry phase was not represented in this sample. Table 4.28 and Figure 4.25 show the frequencies of decay stages within each postmortem interval time range specified in Bass' model. For fresh cases, the mean postmortem interval was 1.44 days and fell within the first day period 87.5% of the time. For bloated, the mean PMI was 5.0 days and occurred within the first day to first week interval 73.9% of the time. For advanced, the mean PMI was 16.56 days and correctly transpired within the first week to first month range 55.6% of the time. Preliminary investigation of the frequencies shown in Table 4.28 indicates that the likelihood of remaining undiscovered within an enclosed environment decreases with the passage of time. Table 4.28 and Figure 4.25 also show that all stages of decomposition were represented within the first week and first month time ranges. This demonstrated a problematic variability of decay rates with extended PMI and suggested that there was variation in the amount of time needed to achieve each stage of decomposition.

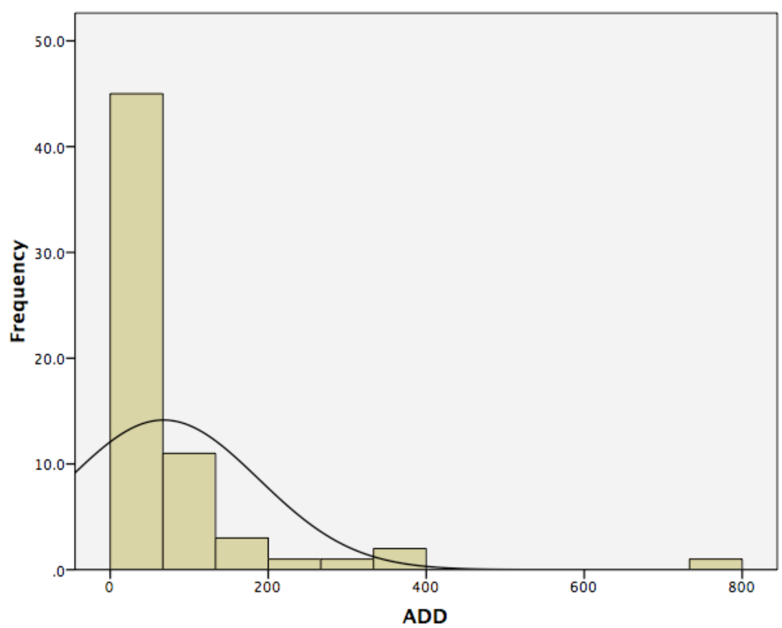
A *Spearman's Correlation* was implemented to test whether or not there was a correlation between the stages of decomposition and the postmortem interval time ranges that Bass created. The correlation between time range and stage of decomposition was significant ($r=0.829, n=64, p\leq 0.000$), indicating that Bass' model accounted for a significant amount of the variation in this sample. Bass' model was therefore an adequate predictor the postmortem interval for this sample. This correlation demonstrates that the data did reflect decomposition variability. Thus, the data were well suited for identifying what taphonomic effects best correlate with time and accumulated degree days, and would therefore serve as good predictors of the postmortem interval.

Figure 4.21—Enclosed Deposition Distribution for PMI Days (n=64).



* Measured in Days

Figure 4.22—Enclosed Deposition Distribution for ADD (n=64).



* Measured in ˚C.

Figure 4.23—Enclosed Deposition PMI Day Range by Bass' Decomposition Stages (n=64).

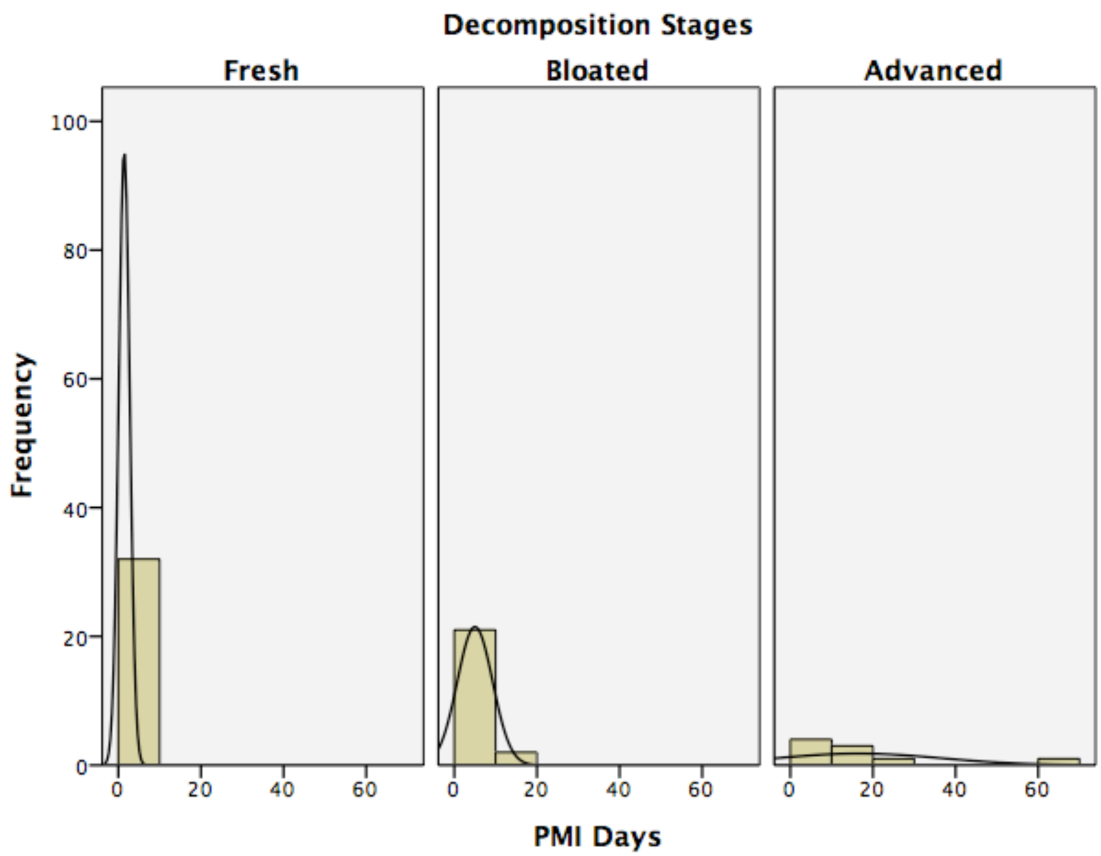


Figure 4.24—Enclosed Deposition ADD Range by Bass' Decomposition Stages (n=64).

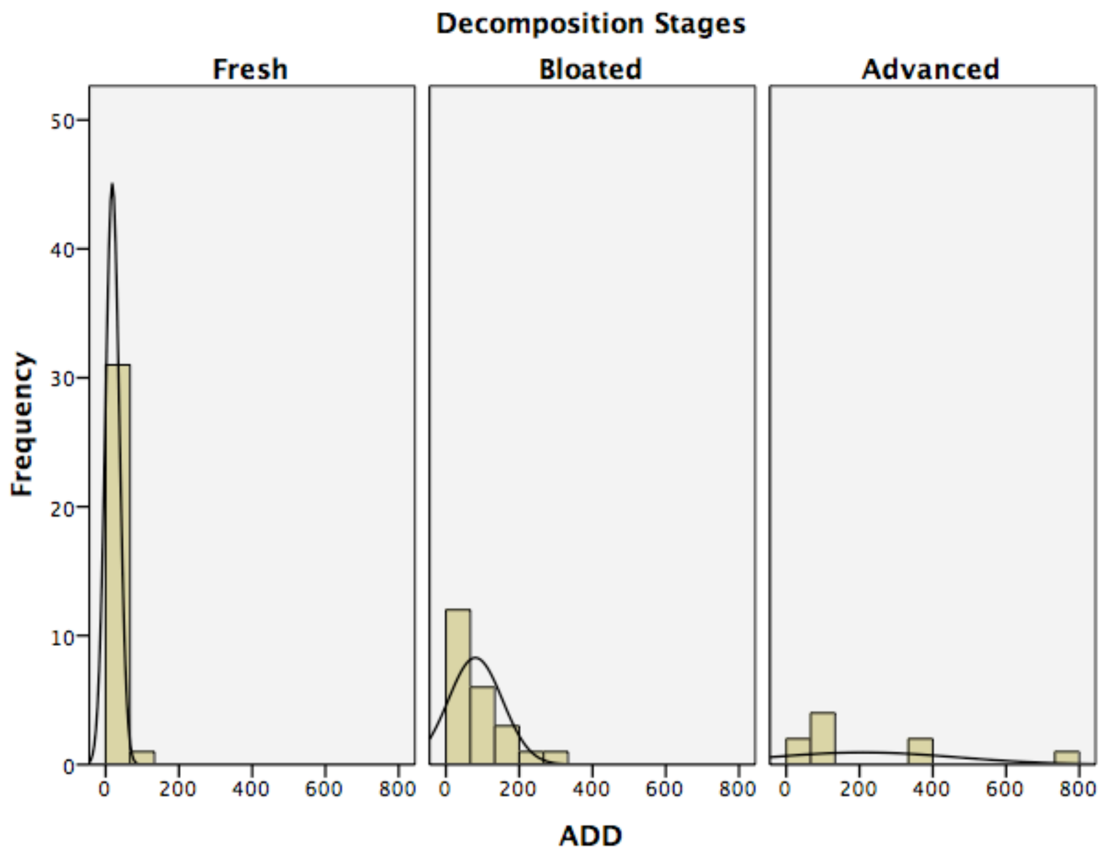


Table 4.26—Enclosed Deposition Descriptive Statistics for PMI Days by Decay Stage.

Stage of Decay	n	PMI Range	$\overline{X}$	s.d.
Fresh	32/67	1-8	1.44	1.34
Bloated	23/67	1-17	5.0	4.27
Advanced	9/67	2-66	16.56	19.87

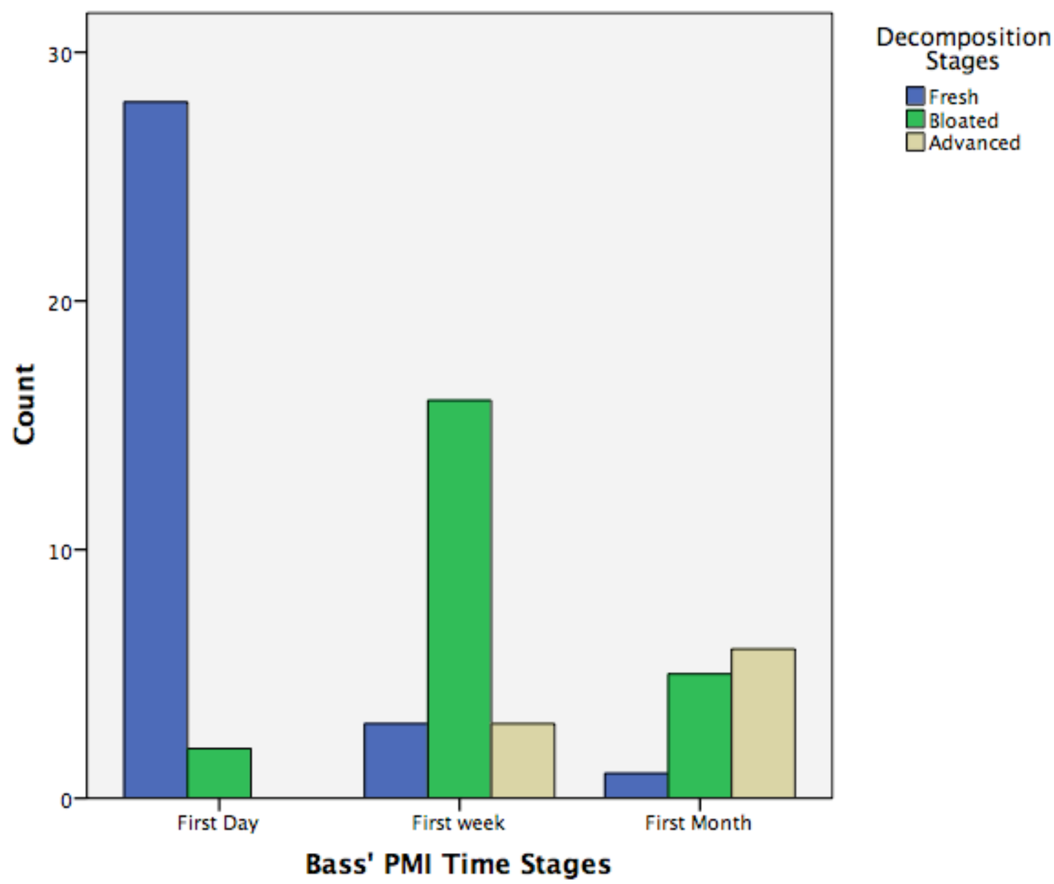
Table 4.27—Enclosed Deposition Descriptive Statistics on ADD by Decay Stage.

Stage of Decay	n	ADD Range	$\overline{X}$	s.d.
Fresh	32	0-82	18.32	18.87
Bloated	23	0-291	80.36	73.84
Advanced	9	9-786	209.75	254.23

Table 4.28—Enclosed Deposition Stage of Decay by PMI Range.

	Fresh		Bloated		Advanced		Total %
	Stage %	Total %	Stage %	Total %	Stage %	Total %	
First Day	87.5	43.8 (28/64)	8.7	3.1 (2/64)	0	0	46.9 (30/64)
First Week	12.5	6.2 (4/64)	73.9	26.6 (17/64)	33.3	4.7 (3/64)	37.5 (24/64)
First Month	0	0	17.5	6.2 (4/64)	55.6	7.8 (3/64)	14.1 (9/64)
> First Month	0	0	0	0	11.1	1.6 (1/64)	1.6 (1/64)
Total	100	50.0 (32/64)	100	35.9 (23/64)	100	14.1 (9/64)	100 (64)

Figure 4.25—Enclosed Deposition Stages of Decay by Bass' Time Ranges (n=64).



Difference in PMI Days and ADD among Decomposition Stages

Nonparametric Kruskal-Wallis tests were employed to test for differences in accumulated degree days among decomposition stages and for PMI days among decomposition stages. For ADD, the *Kruskal-Wallis test* yielded the following results: $X^2=21.651$, $df=2$, $p\leq 0.000$. This revealed that there was a significant difference in the ADD among the stages of decomposition. Table 4.29 shows the results for the *Mann-Whitney U post hoc tests* for ADD; there were significant differences between fresh and bloated cases as well as fresh and advanced cases, but not between bloated and advanced cases. For PMI days, the *Kruskal-Wallis test* yielded the following results: $X^2=29.116$, $df=1$, $p\leq 0.000$. These results indicated that there was a significant difference in PMI days among the decomposition stages. Table 4.30 shows the results for the *Mann-Whitney U post hoc tests*; there were significant differences in the postmortem interval among all stages represented.

Table 4.29—Mann-Whitney U Post Hocs: Decay Stages and ADD.

Comparison	Mann-Whitney U	p-value
Fresh and Bloated	79.0	≤0.000
Fresh and Advanced	11.0	≤0.000
Bloated and Advanced	56.0	=0.045

Table 4.30—Mann-Whitney U Post Hocs: Decomposition Stages and PMI.

Comparison	Mann-Whitney U	p-value
Fresh and Bloated	81.0	≤0.000
Fresh and Advanced	11.0	≤0.000
Bloated and Advanced	56.0	=0.047

Description of Taphonomic Effects by Stage of Decay

To approximate whether or not decomposition within enclosed environments manifested itself in the same manner and at the same rates relative to the assigned stage of decomposition, investigators also identified the individual taphonomic effects located on the remains and the stage of decomposition in which the bodies were discovered. Table 4.31 displays the intrinsic decompositional changes that were identified within this sample for when it was known if they were present or absent. Due to the limitations of retrospective data, the sample sizes varied for every taphonomic effect within each stage of decomposition. The unknown cases exemplified how the variation in police and autopsy records affected what was known for each case.

Within the bloated stage, bloating of the abdomen was documented at a frequency of 91.7% (22/24); however, bloating was still present within 62.5% (5/8) of the "advanced" cases, when putrefactive gases have supposedly been released. This could be problematic when attempting to assign a time range for PMI because the presence of bloating is the primary feature that defines the first day to first week PMI time range. All cases beyond the fresh state possessed decompositional odor, and most bodies' organs were still examinable. These taphonomic effects were not identified as good indicators of stage of decomposition. Lividity was also eliminated as an indicator of decompositional stage.

Skin slippage is a feature that is not expected to occur until the bloated phase and was most prevalent during the bloated stage but was also documented in 18.2% (6/33) of the fresh cases. Skin slippage, marbling, bloating, postmortem blood clotting and the presence of purge fluid all showed the highest prevalence during the bloated phase and could be good predictors for that phase. Green discoloration, mummification, decompositional fluid staining and brain liquefaction were most prevalent during the advanced stage and may serve as good indicators of this stage. However, partial mummification was identified in 17.4% (4/23) of the bloated cases. Skeletonization was only found within 11.1% of the advanced cases (1/9) and this body was less than 25.0% skeletonized. Skeletonization was not represented enough in this sample to know whether or not it is a useful indicator for assigning a body to a stage of decomposition for enclosed remains.

Table 4.31—Enclosed Remains Taphonomic Effects by Decay Stage.

Taphonomic Effect	Fresh	Bloated	Advanced	Total
PMI Range (days)	1.0 - 8.0	1.0 - 17.0	2.0 - 66.0	1 - 66.0
ADD Range	0.0 - 82.0	0.0 - 291.0	9.0 - 786.0	0.0 - 786.0
Taphonomic Effect	Stage %	Stage %	Stage %	Total %
Rigor	84.4 (27/32*)	44.0 (11/25*)	11.9 (1/9*)	59.1 (39/66*)
Lividity	96.9 (32/33)	100 (24/24)	77.8 (7/9)	95.4 (62/65)
Skin Slippage	18.2 (6/33)	95.7 (22/23)	88.9 (8/9)	55.4 (36/65)
Marbling	0	83.3 (20/24)	62.5 (5/8)	38.5 (25/65)
Bloating	0	91.7 (22/24)	62.5 (5/8)	42.2 (27/64)
Green Discoloration	3.0 (1/33)	79.2 (19/24)	87.5 (7/8)	41.5 (27/65)
Purge Fluid	29.0 (9/31)	75.0 (15/20)	40.0 (2/5)	46.4 (26/56)
Mummified Skin	0	17.4 (4/23)	88.9 (8/9)	18.8 (12/64)
Decomp Odor	3.4 (1/29)	100 (22/22)	100 (8/8)	52.5 (31/59)
Decomp Fluid Stain	0	14.3 (3/21)	50.0 (3/6)	10.7 (6/56)
Blood Clot	64.5 (20/31)	86.4 (19/22)	75.0 (6/8)	73.8 (45/61)
Brain Liquefaction	0	31.8 (7/)	57.1 (4/)	18.3 (11/60)
Examinable Organs	90.9 (30/33)	92.0 (23/25)	77.8 (7/9)	89.6 (60/67)

* The total enclosed sample for where the stage of decomposition was known equaled 67, after outliers were removed. However, sample sizes varied for each taphonomic effect by stage of decay. The sample size variability reflects the differentiation between cases that were present/absent versus unknown. Therefore, what looks like missing cases represents where information was unknown.

Descriptions of Intrinsic Taphonomic Effects, PMI and ADD

To identify any decomposition effects that could be appropriate indicators of the postmortem interval, the frequencies of individual taphonomic effects within Bass' time ranges of PMI were described. Table 4.32 shows the decomposition traits that were identified as potentially having a strong relationship with the postmortem interval. The frequencies of how often each effect was present are listed. Due to cases where the presence or absence of an effect was unknown, the sample sizes varied. Figure 4.26 shows the percentage of how often each effect was documented as present within each time range. Table 4.33 shows the descriptive statistics for each trait's postmortem interval (in days) and ADD. This table demonstrates the large range of variability in ADD and PMI days for each trait.

Likelihood of Taphonomic Effects After the First Week of the PMI

The likelihood of the presence of taphonomic effects within and after the first week of decomposition was investigated with *odds ratios*. Table 4.34 – 4.38 show the cross-tabulations of frequency data for taphonomic effects within and after the first week of decomposition. The following taphonomic effects were analyzed: marbling, bloating, green discoloration, mummification and brain liquefaction. For each, the *odds ratio* was calculated as follows: *(ad)/(bc)=odds ratio.* Table 4.39 shows the likelihoods of displaying each taphonomic effect for within one week and after one week of the PMI. This table shows that all examined taphonomic effects were more likely to be present when a body had undergone a postmortem interval of longer than one week. For example, a body is 3.27 times more likely to present marbling after the first week of the PMI, when compared to those without bloating. Conversely, a body is 0.31 times less likely to display marbling within the first week, when compared to those who do not display bloating.

Correlations between Taphonomic Effects, PMI and ADD

Spearman's Correlations were used to identify which of the taphonomic effects listed in Table 4.32 were significantly correlated with PMI days and ADD. The following intrinsic characteristics of the individuals in life were also included: age, height, estimated weight, and estimated BMI. These correlations were conducted to show that individual effects were in fact correlated with the raw ADD variable because the ADD were later transformed for model building (described below). Table 4.40 shows the intrinsic individual characteristics and taphonomic effects that accounted for a significant portion of the variation of PMI and ADD. Age, estimated BMI and height did not correlate well with either and were dropped from the analysis. Surprisingly, the taphonomic effects tended to be more highly correlated with PMI than ADD. Estimated weight was the only intrinsic characteristic of individuals during life that was significantly correlated with ADD.

Table 4.32—Enclosed Deposition Taphonomic Effects and Time Ranges.

Taphonomic Effect	First Day	First Week	First Month	>First Month	Total
	Range %	Range %	Range %	Range %	Total %
Rigor	82.8 (24/29*)	50.0 (11/22*)	25.0 (3/12*)	0	60.3 (38/63*)
Skin Slippage	20.7% (6/29)	86.4% (19/22)	81.8% (9/11)	100 (1)	55.6% (35/63)
Marbling	3.3% (1/30)	70.0% (14/20)	63.6% (7/11)	100 (1)	37.1% (23/62)
Bloating	6.7% (2/30)	80.0% (16/20)	60.0% (6/10)	100 (1)	41.0 (25/61)
Green Discolor	6.7% (2/30)	66.7% (14/21)	80.0% (8/10)	100 (1)	40.3 (25/62)
Purge Fluid	32.1 (9/28)	61.1 (11/18)	71.4 (5/7)	0	46.3% (25/54)
Mummified Skin	0	25.0% (5/20)	54.6% (6/11)	100 (1)	19.7% (12/61)
Decomp Odor	3.8% (1/26)	94.7% (18/19)	90.0% (9/10)	100 (1)	51.8% (29/56)
Blood Clot	62.1% (18/29)	85.7% (18/21)	80.0% (8/10)	100 (1)	73.8% (45/61)
Brain Liquefaction	0	31.6% (6/19)	44.4% (4/9)	100 (1)	19.0% (11/58)

* The total enclosed sample for where the PMI was known equaled 64, after outliers were removed. However, sample sizes varied for each taphonomic effect by time range. The sample size variability reflects the differentiation between cases that were present/absent versus unknown. Therefore, what looks like missing cases represents where information was unknown.

Figure 4.26—Enclosed Context Percentages of Taphonomic Effects Present for Each Time Range.

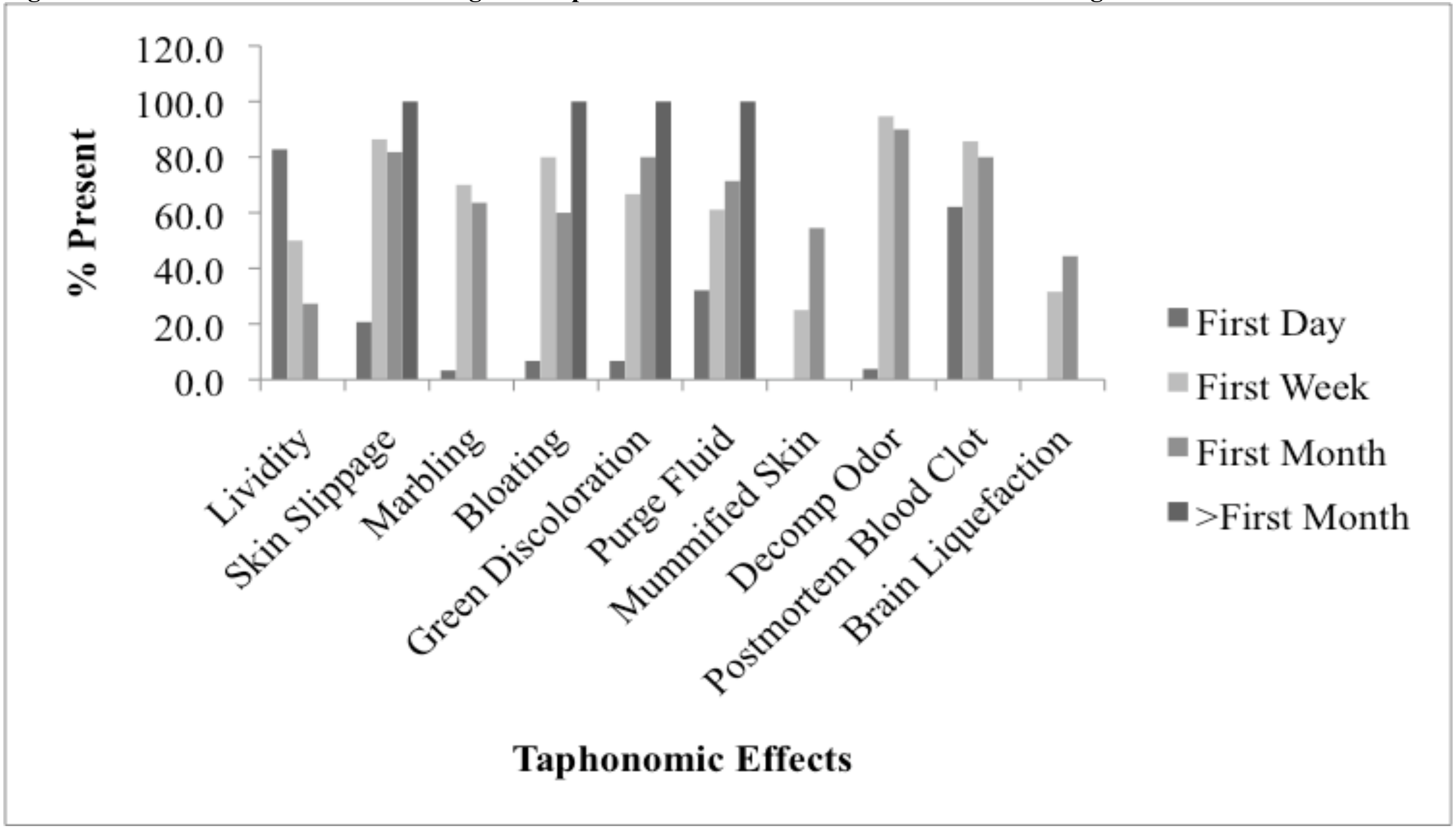


Table 4.33—Enclosed Deposition PMI for Taphonomic Effects.

Taphonomic Effect	n	Range		$\overline{X}$		s.d.	
		PMI*	ADD**	PMI*	ADD**	PMI*	ADD**
Rigor	38	1-10	0-150	2.25	29.33	2.21	36.88
Skin Slippage	35	1-66	0-786	7.40	104.17	11.65	152.20
Marbling	23	1-66	0-786	9.00	129.42	13.53	167.69
Bloating	25	1-66	0-786	7.60	126.91	12.91	167.72
Green Discoloration	25	1-66	0-786	8.88	135.60	13.23	170.20
Purge Fluid	25	1-17	0-336	4.22	75.07	4.58	92.54
Mummified Skin	12	2-66	31-786	13.33	210.51	17.56	218.22
Decomp Odor	29	1-66	0-786	8.34	112.22	12.36	152.84
Blood Clot	48	1-66	0-786	5.26	82.79	10.18	139.66
Brain Liquefaction	11	2-66	0-786	12.64	191.11	18.50	221.83

* Measured in Days
** Measured in ˚C

Table 4.34—Enclosed Deposition Frequency of Marbling by Time Range.

Marbling	> 1 Week	≤ 1 Week	Total
Present	(a) 7	(b) 15	22
Absence	(c) 5	(d) 35	40
Total	12	50	62

Table 4.35—Enclosed Deposition Frequency of Bloating by Time Range.

Bloating	> 1 Week	≤ 1 Week	Total
Present	(a) 7	(b) 18	25
Absence	(c) 4	(d) 32	36
Total	11	50	61

Table 4.36—Enclosed Deposition Frequency of Green Discoloration by Time Range.

Green Discoloration	> 1 Week	≤ 1 Week	Total
Present	(a) 9	(b) 16	25
Absence	(c) 2	(d) 35	37
Total	11	51	62

Table 4.37—Enclosed Deposition Frequency of Mummification by Time Range.

Mummification	> 1 Week	≤ 1 Week	Total
Present	(a) 6	(b) 5	11
Absence	(c) 6	(d) 44	50
Total	12	49	61

Table 4.38—Enclosed Deposition Frequency of Brain Liquefaction by Time Range.

Brain Liquefaction	> 1 Week	≤ 1 Week	Total
Present	(a) 4	(b) 6	10
Absence	(c) 6	(d) 42	48
Total	10	48	58

Table 4.39—Likelihood of Taphonomic Effects by PMI Time Range.

Taphonomic Effect	≤ 1 Week	> 1 Week
Marbling	0.31	3.27
Bloating	0.32	3.11
Green Discoloration	0.10	9.84
Mummification	0.11	8.8
Brain Liquefaction	0.21	4.67

Table 4.40—Spearman's Correlations between Taphonomic Effects, PMI and ADD.

Taphonomic Effect	n	PMI Days		ADD	
		r	p≤	r	p≤
Rigor	63	-0.467	0.000	-0.422	0.001
Skin Slippage	63	0.573	0.000	0.431	0.000
Marbling	62	0.628	0.000	0.486	0.000
Bloating	61	0.583	0.000	0.547	0.000
Green Discoloration	62	0.65	0.000	0.555	0.000
Mummified Skin	61	0.534	0.000	0.546	0.000
Decomposition Odor	56	0.810	0.000	0.619	0.000
Brain Liquefaction	58	0.510	0.000	0.442	0.001
Weight in Kg	63	-0.157	0.218	-0.393	0.001

Description of Extrinsic and Epidemiological Factors

It was of interest to identify environmental factors that influenced the velocity of decay within enclosed environments. Among known cases, only 12.3% (7/57) cases with fly colonization were documented in this sample: 11.1% (2/18) within the bloated stage and 71.4% (5/7) within the advanced stage. For vehicles only, 33.3% (2/6) of the cases presented evidence of fly colonization. No cases of beetle colonization were identified in the indoor records. The only documented case of carnivorous activity was found within the first week and "bloated" range. Based on these findings, necrophagous activities are not good indicators for the postmortem interval or the accumulated degree day interval for enclosed spaces.

Preliminary trends suggested that synthetic fabrics and containers might retard the pace of human decay. After the two subadults were removed from the analysis, there were two bodies that were still fresh after the first day but within the first week of decomposition and both bodies decomposed on synthetic surfaces, such as carpet, bedding and a car seat. They were also both moderately to fully covered by clothing (≈50.0-100.0%). Of the four bloated individuals whose postmortem interval was estimated as being within the first month, one (25.0%) had been wrapped within a blanket. This body and another were both found on bedding, and there were two others who (50.0%) had decomposed on a couch and a recliner.

All three advanced cases that were within their first week of decomposition were also located within vehicle containers and were mostly covered with clothing (≈50 – 75%). The victims were all seated in an upright position where their upper bodies would have been in position to receive sun exposure through the windows. For at least two of these cases, it was known that the windows were closed. This suggested that vehicle deposition greatly accelerated the rate of human decay. One of the bodies that were found in a car with closed windows had a postmortem interval of only two days, and yet maggots had decimated a large portion of the soft tissue (approximately 75.0-95.0% complete).

Relationship between Extrinsic Factors, PMI and ADD

Spearman's Correlations were used to test for correlations between PMI and ADD as well as any environmental and burial factors that could be suitable predictors of the postmortem interval. These variables included: the percent of the body covered by clothing, whether or not there was a container, use of AC or heat, room in home, and surface of deposition. Table 4.41 shows the variables that were significantly correlated with ADD. Interestingly, the season of decomposition and the use of air conditioning or heat were significantly correlated with ADD but not with the postmortem interval. The presence of necrophagous activity was significantly correlated with both PMI and ADD. These variables could be useful in the prediction of the accumulated temperature since death.

Table 4.41—Extrinsic and Burial Factors Correlated with ADD.

Variable	ADD Correlation		
	n	r	p≤
Use of AC/Heat during the PMI	19	-0.463	0.046
PMI Seasons	64	-0.453	0.000
Necrophagous Activity	55	0.457	0.000

Transformations of PMI and ADD

It was determined that ADD and PMI days were not normal. Several strategies were attempted to avoid transformations, such as separating the PMI days and ADD by stage of decay and by various time intervals. Unfortunately, these attempts were unsuccessful at making either ADD or PMI normal and thus transformations were attempted. Transformations for the postmortem interval in days were unsuccessful. Unfortunately, an alternative and comparable model that predicts the PMI could not be created.

For model building, accumulated degree days were transformed into the log10 of accumulated degree days (LogADD) because this was the only transformation that made the dependent variable follow a normal distribution (*Shapiro-Wilk=0.986, df=56, p=0.144*). Figure 4.27 shows the distribution for the LogADD. The enclosed sample only had data for bodies whose PMI ranged from 1 – 66 days and whose ADD ranged from 0 – 786 ˚C. As a result, this model is only adequate for prediction of postmortem intervals and ADD that fall within these ranges. The LogADD ranged from 0.0 – 2.90 (*mean=1.51, s.d.=0.56* $\log_{10}$ADD).

Relationship Between Independent Variables and LogADD

Table 4.42 shows a variety of factors that were considered as potentially good predictors for the LogADD. There was evidence of multicollinearity among some of the intrinsic decompositional effects such as bloating and green discoloration. Correlations among the independent variables can make it difficult to reliably estimate the slopes of the variables that are highly correlated. However, the *Spearman's Correlations* identified these taphonomic effects as the most important predictors of the LogADD. It was clear that decomposition effects were correlated with the temperature accumulation during the PMI and these taphonomic changes were often the only evidence available to estimate this interval. Despite the multicollinearity, they were included.

Although height and the percentage of the body covered by clothing were not significantly correlated with ADD, they were significantly correlated with the LogADD. The height data were also normal (*Shapiro-Wilk=0.978, df=56, p=0.397*) and so both height and the percent of body coverage by clothing were reconsidered in the analysis as possible predictors. Estimated weight and BMI could not be considered for model building because they were not normal and transformations were unsuccessful. The use of AC or heat was not significantly correlated with the LogADD; however, it was significantly correlated with the untransformed Y and so it was considered for model building.

Figure 4.28 shows height plotted against the LogADD. Height and the LogADD did show a clear linear relationship, where as the LogADD increases, height decreases. Therefore, height met both the assumptions of normality and linear relationships with the LogADD and was included for model building.

Figure 4.27—Distribution of LogADD.

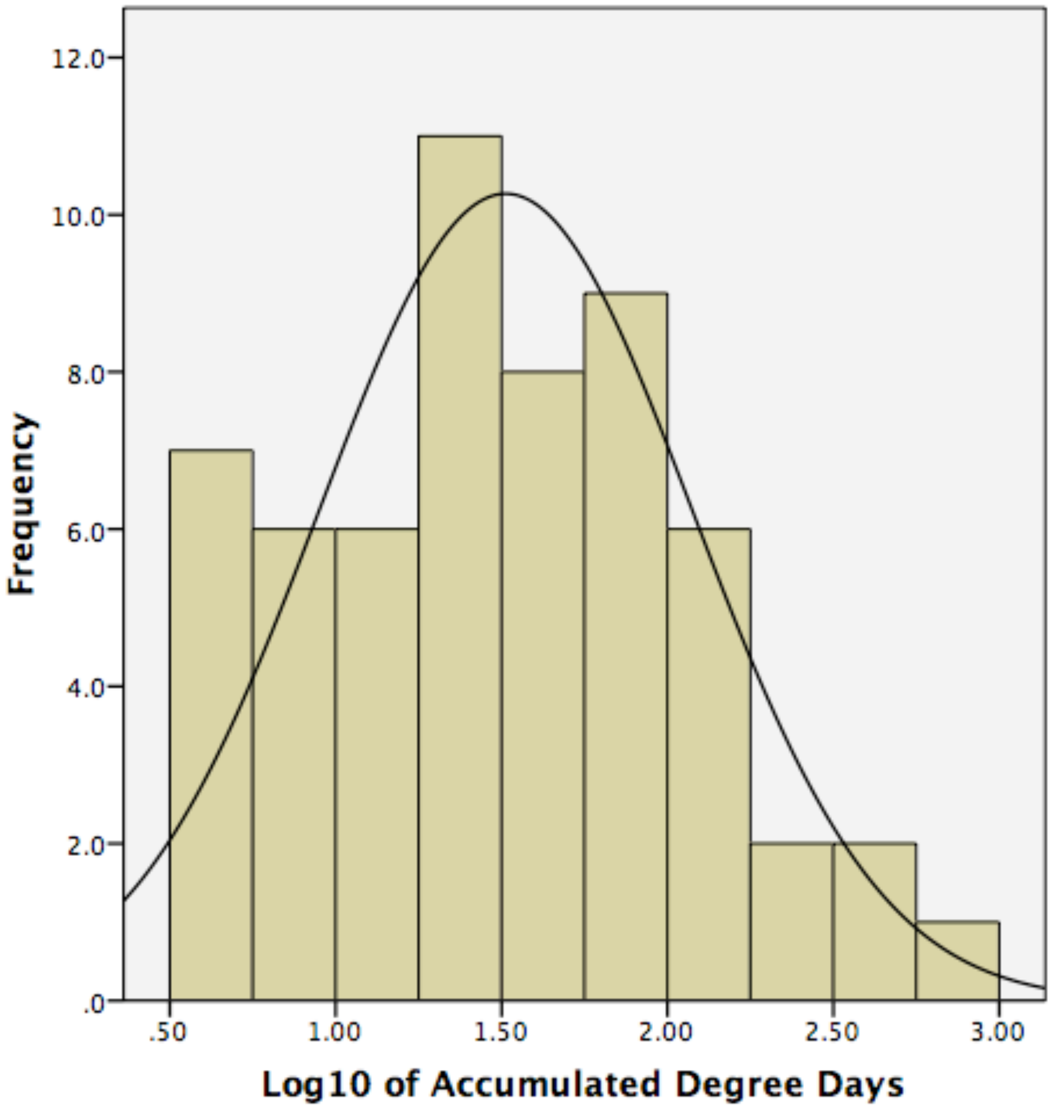
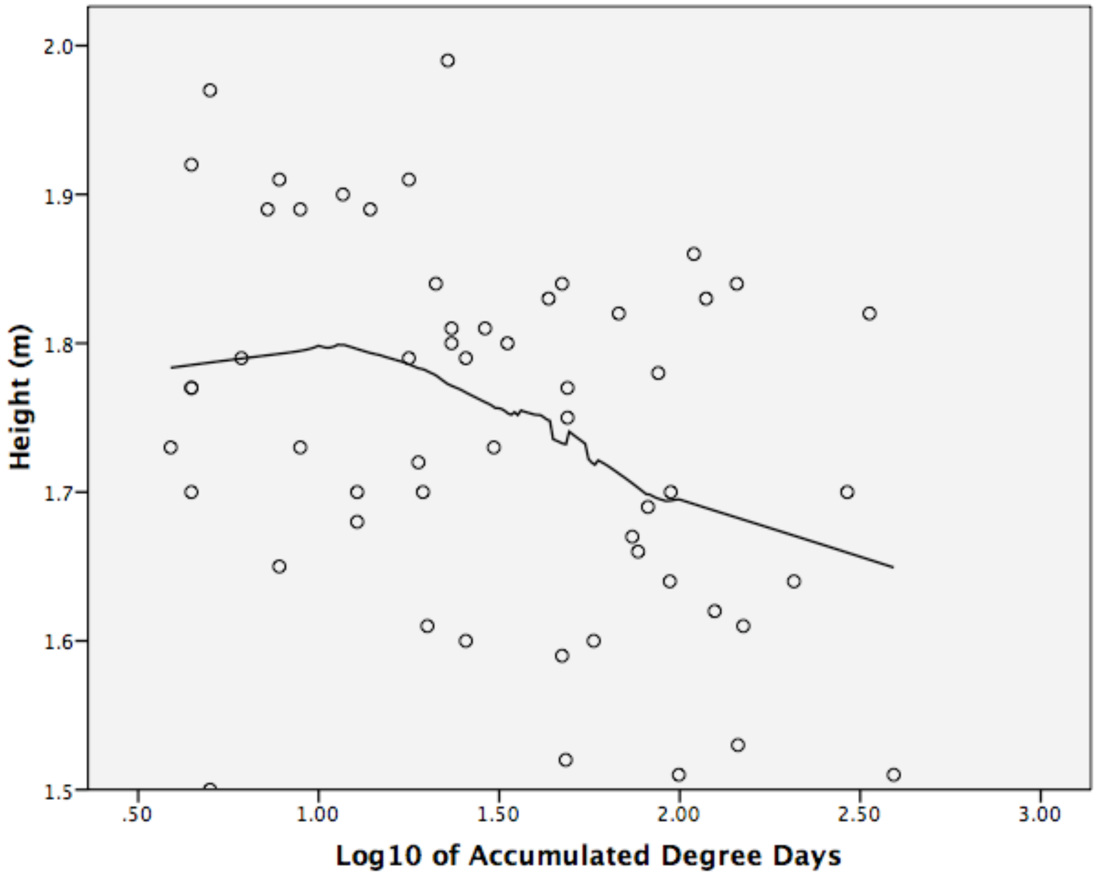


Table 4.42—Likely Predictors of LogADD.

Variable	Correlation with LogADD		
	n	r	p≤
Rigor	56	-0.544	0.000
Skin Slippage	56	0.359	0.007
Marbling	55	0.485	0.000
Bloating	54	0.549	0.000
Green Discolor	55	0.562	0.000
Mummified Skin	54	0.518	0.000
Decomposition Odor	49	0.608	0.000
Brain Liquefaction	51	0.500	0.000
Height	56	-0.329	0.013
% of Body Covered by Clothing	50	-0.281	0.048
Use of AC/Heat during the PMI	16	-0.287	0.280*
PMI Seasons	57	-0.412	0.001
Necrophagous Activity	48	0.492	0.000

* The use of air conditioning or heat variable was not significantly correlated with the transformed ADD (Log_{10}ADD). However, it was significantly correlated with the untransformed variable, ADD. Thus, it was still considered for creating the multiple linear regression model. The use of AC/Heat variable was selected for the model and shown to independently account for a significant portion of the variation in the model.

Figure 4.28—Height in Meters and LogADD.



* Line represents Lowess Line.

Multiple Regression Model

All variables listed in Table 4.42 except the presence of necrophagous activity were considered for the regression model. When the presence of necrophagous activity was used, the adjusted R^2 was substantially lowered and so this variable was manually removed. The procedures of forward selection, backwards elimination and stepwise regressions were used to determine what model would be the best model. Stepwise regression yielded the model of choice, which incorporated the following five variables: decomposition odor, use of air conditioning or heat, marbling, brain liquefaction, and mummification of soft tissue. This model was chosen based on the following criteria: adjusted R^2, Mean Squares Error (MSE), Mallows' Prediction Criterion, the F ratio and the individual t scores.

The ANOVA yielded the following statistics: $F=40.807$, $df=5, 5$ *and* $p \leq 0.000$. The ANOVA's significance level demonstrates that the independent variables account for a significant amount of the variation in the LogADD. The standard error of the estimate is $S.E.=0.118$, which should be added and subtracted from a predicted ADD so as to provide a range. The mean squares error $MSE=0.014$, which is the second to lowest MSE for all possible models and indicates that there is less variation not accounted for in this model than all others except one.

Table 4.43 shows the R values and the Mallows' Prediction Criterion for this model. The adjusted R^2 value shows that 95.2% of the variation in the LogADD has been explained by this model. Overall, these two statistics indicated that this is a strong model, despite the evidence of multicollinearity that was first observed among some of the variables.

Table 4.44 shows the t-values, tolerance and VIF for all predictive variables. Below is the equation (4.1) to predict the effect of a predicted X value on the LogADD. This equation showed that if decomposition odor was increased by one and all other independent factors were held constant, the LogADD would increase by 0.61.

$$\mathbf{Log_{10}(\hat{Y})=1.227+0.61(Odor)-0.512(AC/Heat)+0.714(Marbling)-0.414(Brain\ Liquefaction)-0.268(Mummification)+\epsilon\ [\pm 0.118]} \tag{4.1}$$

The t-values for all independent variables were significant except for brain liquefaction and mummification. These scores indicated that all independent variables except for liquefaction and mummification accounted for a significant portion of the variation in LogADD. Mummification and liquefaction did not account for a significant portion of the variants by themselves, but did to contribute as predictors to the total variation accounted for by the model. Both tolerance and VIF values indicate that there were no problems in the model associated with multicollinearity.

Table 4.43—R statistics and Mallows' Prediction Criterion.

Model Statistics	
R	0.988
R^2	0.976
Adjusted R^2	0.952
Mallows' Prediction Criterion	2.643

Table 4.44—T-values, Tolerance and VIF for Predictive Model.

Model	Unstandardized Coefficients		Standardized Coefficients	t	p	Collinearity Statistics	
	B	S. E	Beta			Tol.	VIF
Constant	1.227	0.064		19.191	≈0.000		
Decomposition Odor	0.610	0.099	0.591	6.157	0.002	0.519	1.925
AC/Heat	-0.512	0.090	-0.479	-5.659	0.002	0.668	1.497
Marbling	0.714	0.151	0.668	4.719	0.005	0.239	4.193
Brain Liquefaction	-0.414	0.170	-0.359	-2.432	0.059	0.219	4.556
Mummification	-0.268	0.144	-0.150	-1.856	0.123	0.733	1.364

* Excluded Variables: skin slippage, bloating, green discoloration, height, % of body covered by clothing, seasons of PMI

Model Evaluation

Figure 4.29 shows the histogram of the residuals and Figure 4.30 shows the residuals' normal plot. Both plots allude to problems with this model where variation of the LogADD has not been accounted for. The normality for the unstandardized and standardized residuals were tested and were normal (*Shapiro-Wilk=0.945, df=11, p=0.577* for both). Although the histogram was not distributed along the bell-curve, the residuals were highly statistically insignificant. The residuals could not be plotted against the LogADD to identify any departures from linearity or homoscedasticity because all the independent variables were categorical. Overall, this was the best model discovered.

Figure 4.29—Histogram of Residuals.

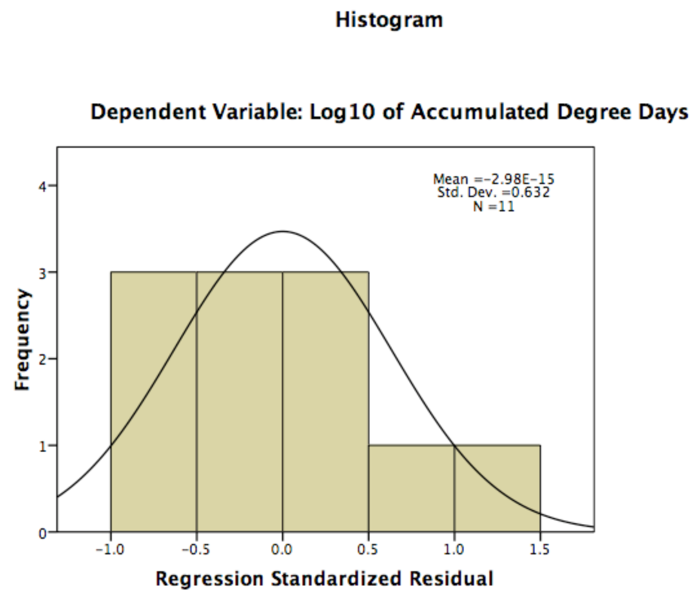
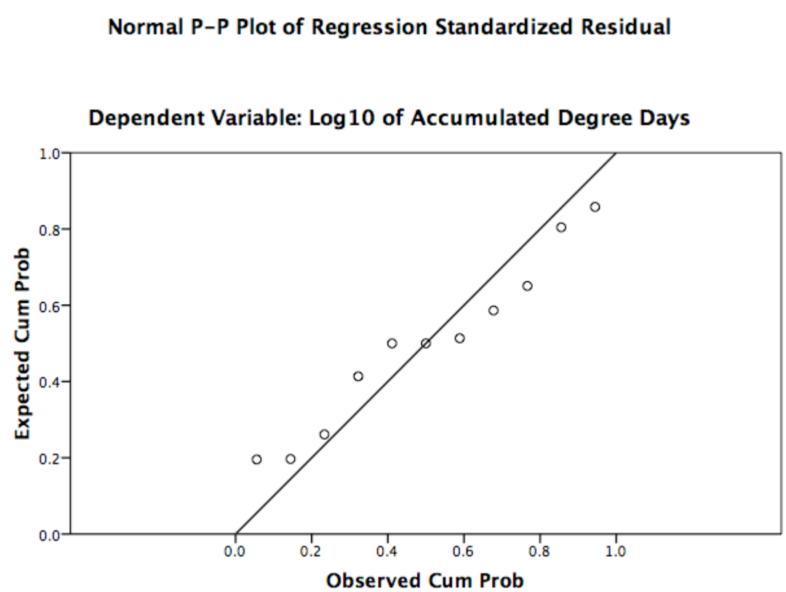


Figure 4.30—Normal Plot of Residuals.



Chapter 5

Discussion

Demographic Profile for All Unaccompanied Deaths

A demographic analysis of the people who composed this sample began to illustrate the collective identity of individuals who die alone in the Midwest. However, the small sample sizes investigated within this study necessitate caution in the interpretation of general trends. The sample was overwhelmingly composed of adult European Americans and mostly men, which reflect on the greater population from which it was drawn, as most Nebraskans are of European ancestry. It was unknown as to why women and children were not more prevalent in the sample, but the former probably indicates that most children are unlikely to die alone.

Interestingly, sex was independent of age at death and manner of death, but there was a relationship between cause of death and sex. It was found that men were dying both of heart disease and drugs or alcohol, while women were primarily dying of drugs or alcohol but not heart disease. These common causes of death communicate aspects of American lifestyles such as high cholesterol diets and the tendency towards excessive consumption that promotes poor health and early death.

Age was related to manner of death, where younger individuals suffered unexpected homicidal, suicidal or accidental deaths, while older individuals often experienced natural deaths. The association of natural deaths to older individuals and unexpected deaths to younger people relates to the common causes of death, namely heart disease and drugs/alcohol. It was found that suicides and accidents were more likely to involve drugs and alcohol than were natural deaths. However, the retrospective nature of the data made it likely that drug and alcohol involvement in solitary deaths were highly underrepresented. Autopsy reports do not always provide information about illegal substance use for chronic users who die a natural death. Drugs and alcohol are also less likely to be detected as time passes. Additionally, unless a case was solved it is unlikely that death investigation reports would provide information about substance use of offenders in homicide cases. Yet these results indicated that deaths from acute consumption of alcohol or drugs were more common than deaths from long-term substance abuse.

Based on these findings, unaccompanied deaths in the Midwest were characterized by Euroamericans men who were middle aged and died natural deaths from heart disease or drug and alcohol abuse. Women were not as prevalent but tended to die from drugs and alcohol abuse and not heart disease. In contrast, the younger individuals in the population died violent and unexpected deaths. The demographic profile of unanticipated deaths could be useful in future analyses of how lifestyle is reflected in death. Also, demographic information could be used for developing investigative techniques for when a decedent is discovered and the events surrounding his or her demise must be reconstructed.

Demographic Profile by Context and PMI

An analysis of the demographic profile in conjunction with epidemiological variables such as manner of death allowed for the anthropological model to account for who was at risk of dying alone and being discovered in each context. Victim demographics revealed trends in collective identity (Kimmerle and Baraybar 2008; Kimmerle *et al.* 2009) while the locations of where bodies were discovered provided information on the circumstances that led to their deaths (Morten and Lord 2002). The anthropological model enabled the relationship between collective identity and perimortem events to be linked with the postmortem interval. Six main contexts of deposition were identified: outdoor near-surface, outdoor subsurface, submerged, exhumed, within a vehicle, and indoors.

Collective identity and human behavior surrounding a death event dictated the taphonomic scenario (Kimmerle *et al*. 2009; Morten and Lord 2002). It was found that there was no relationship between the length of the postmortem interval and the manner of death. However, this analysis only considered the PMI for suicides, accidents, and natural deaths. The descriptive statistics showed that homicides had the largest range and the highest means and medians for the postmortem interval (Table 4.12). Although the small sample size for homicides precluded their inclusion in the analysis, the descriptive statistics indicated that people who die from homicides tend to remain undiscovered longer than people who die from other circumstances. These results were congruous with the conditions surrounding a homicide. The depositions that resulted from homicides reflected body disposal. Similarly, most outdoor near-surface (62.5%, 5/8) and all subsurface finds (2/2) resulted from traumatic homicides. For near-surface depositions, the PMI were highly variable, but most cases (57.1%, 4/7) had a PMI longer than four months. The two subsurface depositions had PMI of three months and “years.”

Although the small sample size for homicides (9/85) requires caution in interpretation, the results suggest that homicides tend to have longer PMI and are more likely to be found in an outdoor location due to the nature of the death event. Similarly, outdoor near-surface and subsurface contexts were characterized by homicides, body disposal, and extended PMI. These trends demonstrated how human behavior surrounding the death event affects location of deposition and the time a body remains undiscovered.

In contrast, exhumed bodies were all adult males with questionable circumstances surrounding their deaths. Exhumations are typically executed when family or law enforcement wish to reexamine the body for clues that inform on cause and manner of death. All (3/3) aquatic depositions were men and resulted from accidental deaths where movement of the body reflected fluvial transport. The water sources were either lakes or a river dam that were open to the public, and so 66.6% (2/3) of the cases were discovered within days of the death event. Most decedents were discovered within enclosed environments, yet only 2.9% (2/69) of deaths within this context resulted from homicides. Consequently, enclosed depositions were not likely to result from homicide or from body disposal. Rather, vehicle depositions were largely results of suicides (71.4%, 5/7). Indoor deaths were primarily natural deaths, although other scenarios were represented. This implied that an enclosed deposition resulted when the body remained *in situ* after death. Collectively, vehicle depositions may be indicative of suicide, while indoor depositions are likely to result from natural or accidental deaths. Aquatic, vehicular and indoor depositions were also characterized by shorter PMI, the longest one being 66 days. Shorter PMI were thus associated with non-homicidal manners of death and no disposal of the body.

Within the enclosed context, the two cases discovered in hotel rooms represented the only cases that were indoor but were not within a home or vehicle. Although inferences on Cases 17 and 18 must remain limited, there was a trend in contextual identity between the two men. The information pointed to two men who were both living somewhat lonely lifestyles, who were far away from their homes, and who had a history of drugs and a doleful disposition at the times of their deaths.

By incorporating a model that considered epidemiological and demographic factors (Kimmerle and Baraybar 2008), this study revealed demographic information about who it was who died alone and remained undiscovered for variable amounts of time. Further, it allowed for linkages to be made between victim collective identity, perimortem circumstances and the postmortem interval. Investigation of decedents' demographic profiles, manners of death and PMI among various contexts showed that where a body was found was reflective of the nature of a victim's demise (Morten and Lord 2002) and contributed towards the time frame of which they remained undiscovered. Specifically, outdoor near-surface and subsurface settings were indicative of homicide; vehicle contexts were suggestive of suicides; indoor environments were indicative of natural and accidental deaths; and aquatic depositions were suggestive of accidental deaths. These results reflected trends in how collective identity and context of deposition was linked to human behavior surrounding the death event, which in turn affected each victim's PMI. While not directly comparable, these results complemented the trends in identity, depositional context and behavior discussed by Morten and Lord (2002) and Kimmerle *et al*., where "(t)he contextual and environmental factors need to be part of the case profile (2009:185)."

The small sample sizes make it unclear as to whether or not these trends are generalizable beyond the idiosyncratic scenarios presented here. Yet the data imply that a body's depositional context is reflective of events surrounding the death and also sets the parameters for taphonomic changes (Morten and Lord 2002). Inclusion of epidemiological factors in death investigation is valuable for identifying behavioral and demographic patterns indicative of those whose lives and deaths have become disconnected from society (Kimmerle and Baraybar 2008; Kimmerle *et al*. 2009). When a body is discovered, consideration should be given to the depositional context in conjunction with the victim's identity to provide investigative leads for reconstruction of perimortem events.

Taphonomy, the Postmortem Interval and ADD

Previous research has shown that the location of deposition determines the environmental variables introduced and sets the parameters for the rate of decay (Galloway 1997; Galloway *et al.* 1989; Komar 1998; Mann *et al.* 1991; Morten and Lord 2002; Rodriguez and Bass 1985; Roksandic 2002; Voss *et al*. 2008). The multiple variables involved in decomposition are determined by the environmental and cultural components that are present when a body is deposited (Grupe 2007; Lyman 1994). In any given environmental context, these variables impact one another so that generalizations are difficult to make among different settings (Mann *et al*. 1990; Lyman 1994; Sorg and Haglund 2002). Further, the PMI and ADD ranges for each stage were large and overlapping, indicating that there were many confounding factors being conflated together. For example, in Figure 4.16, the mean PMI for dry cases only displayed up to 500 days, but the actual mean PMI for dry cases was 1,378.25 days. In contrast, the mean PMI days for advanced cases was only 20.42 days. The mean PMI days demonstrate the large discrepancy in time intervals among stages of decay. Therefore, while Bass' model did accounted for 80.1% of the variation when all contexts were combined, separate analyses were conducted for each context as a way to partially control for the environment.

<u>*Near-Surface Depositions*</u>

Bass' (1997) model was created based on bodies that underwent decay in wooded outdoor surface environments. The context used for his model was most consistent with the outdoor near-surface context of this thesis. Therefore, it was expected that the near-surface subset's postmortem intervals would most accurately fit within the time frames associated with each level of decomposition in Bass' model. Despite the climatological disparity between Nebraska and Tennessee, the near-surface sample's stages of decay were found to be remarkably consistent with Bass' predicted time frames for each stage of decomposition. Although the sample with known PMI was small (7/7), these results suggested that Bass' model might yield accurate results if it were to be applied in the Midwest.

Additionally, the extrinsic variables associated with decay in Nebraska's outdoor near-surface environment closely modeled those described by Bass (1997) for Tennessee. Bass (1997) attributed most of the soft tissue removal of surface deposited carcasses to insect activity, and 75.0% (6/8) of the Nebraska cases had been colonized by insects. These results are consistent with the findings from Rodriguez and Bass (1983) and Bass (1997), where insect activity will greatly contribute to the rate of decay in an outdoor surface setting. Canine and other animal scavenging also played a role in the destruction of soft tissue for 37.5% (3/8) of the near-surface remains. Canine scavenging was identified through tooth markings and disarticulation of the remains that were consistent with the literature (Haglund 1997a, b). The contribution of canine scavenging towards decay was consistent with Komar's (1997) findings for decomposition within Canada. The small sample size for outdoor near-surface depositions precludes anything beyond general description. However, the descriptive data showed that the rate of decay and the identified environmental factors were consistent with the literature for decomposition in outdoor surface environments.

While the timing of intrinsic changes could not be quantified for this context, taphonomic effects were described in conjunction with the PMI time rages used by Bass (1997) so that future research can continue to build on identifying when the intrinsic factors for this environment actually occur. Based on the frequencies of which individual taphonomic effects were identified during each time frame, skin slippage, marbling, mummified skin, odor, blood clots, liquefied brain tissue, and examinable organs could be good predictors of the first month time range for the postmortem interval. Soil stain was the only taphonomic effect that is unique to postmortem intervals longer than one month within this sample. The degree of skeletonization was seen to progress with extended PMI time ranges. These frequencies indicated that the degree of skeletonization could be a good indicator of the postmortem interval. Although this sample was far too small to make robust generalizations, the frequencies did provide some evidence for intrinsic effects that might predict PMI. Description of the intrinsic effects also yielded some information on the time ranges for when certain taphonomic effects should manifest themselves on a set of remains in an outdoor near-surface Midwest environment.

Subsurface Depositions

While there were only two subsurface cases, both cases exemplified the many intrinsic, extrinsic and epidemiological factors that can confound estimation of PMI when a single case is investigated. The first case (Case 9) demonstrated a pattern that was compatible with a decelerated rate of decay, while the second case (Case 10) demonstrated trends that were consistent with a surface deposition due to the shallow nature of the grave.

The first case (Case 9) was that of a small juvenile. This case represented what might be encountered when a small body decomposes underground during the winter. This case was in the bloated stage of decomposition and had a postmortem interval of approximately three months. Her postmortem interval was much longer that what would be expected for a surface-deposited body in a bloated stage of decay. The rate of decay was consistent with Rodriguez and Bass' (1985) study of subsurface decomposition. Subsurface burials tend to progress towards skeletonization at a slower rate than other contexts because the soil tends to hold the temperature stable and prevent outside environmental factors such as fly larvae from reaching the remains (Rodriguez and Bass 1985).

In addition to burial, there were several other factors identified that could account for this decelerated rate of decay. The child's body was wrapped in a blanket "container." Like clothing, a blanket could have acted as a barrier to the body and decelerated the rate of decay (Galloway 1997; Galloway *et al*. 1989; Komar 1998; Manhein 1997; Mann *et al*. 1990). The body was covered in adipocere. Where present, adipocere could have preserved the remains and slowed the pace of decay (Perper 2006). The small body size and differential proportions of body tissues such as adipose and skeletal tissue may also have contributed to the decelerated rate of decomposition. Lastly, the body decomposed during the winter months, so that the ADD were low. Research on temperature and decomposition show that low temperatures held constant by burial in soil could have resulted in a slower rate of decay than what might be expected for Case 9 (Clark *et al*. 1997; Gill-King 1997; Manhein 1997; Megyesi *et al*. 2005; Perper 2006; Rodriguez and Bass 1985). This case study exemplifies the interaction among intrinsic, extrinsic and epidemiological factors inherent to estimating the postmortem interval. To accurately predict the PMI for this case, an anthropological model would need to be constructed that accounted not only for temperature, but also body size and barriers to the body.

The second case (Case 10) was the adult male who was found in a shallow subsurface grave and had an estimated PMI of "years." The state of the remains and the taphonomic influences that were present indicated that this case experienced similar environmental pressures that a body would encounter on the soil surface. This was likely due to the shallow depth of the grave (Rodriguez and Bass 1983). The shallow nature of the grave indicates that the body was not well protected from environmental factors, and may have been almost equally susceptible to outdoor environmental influences as a surface deposition (Rodriguez and Bass 1985).

Roots had grown back through the grave, which Rodriguez (1997) estimates to occur after the ground remains undisturbed for approximately a year. However, roots tend to grow back more quickly in shallow graves because there were fewer disturbances to the roots when the grave was dug (Rodriguez 1997; Rodriguez and Bass 1985). Being that the grave had existed for years before discovery, plant growth would have had time to reoccupy the area and could have accelerated the rate of decay for Case 10.

It is likely that the temperatures and temperature fluctuations that this body encountered were similar to the surface temperatures for the same area (Rodriguez 1997; Rodriguez and Bass 1985). Rodriguez and Bass (1985) found that flies could gain access to remains that were buried one foot subsurface. Further, bodies buried one foot subsurface emit odors from the soil that attract flies (Rodriguez 1997). The deepest portion of Case 10's grave put nine inches of soil above the body. The shallow burial of

Case 10 must have adequately communicated decompositional odors to the ambient environment that attracted canine and insect scavengers. This can be inferred by the degree of insect interaction and canine scavenging that the body was subjected to. The presence of pupae casings and scavenger gnaw marks indicate that this partially exposed body was vulnerable to external forces that influence the rate of decay.

In addition to the identified environmental influences, the taphonomic state of the remains was consistent with Bass' (1997) description of surface deposited human remains in the dry phase. Bass describes that dry surface remains may possess bleaching and green staining from plant algae in the surrounding environment. The exposed bones from Case 10 exhibited both bleaching and green discoloration. Therefore, Case 10 represented a shallow subsurface deposition that was both compatible with the taphonomic effects described by Bass (1997) in regards to the dry, skeletonized surface remains as well as Rodriguez and Bass' (1985) superficial subsurface remains. To estimate the PMI for Case 10, one would need to account for the degree that soil depth acted as an insulator and barrier to the body.

Although there were not enough subsurface cases to quantify the relationship between extrinsic factors and taphonomic changes, Cases 9 and 10 exemplified the many variables that should be considered as influential to the rate of decay during a death investigation. Additionally, discussion of the scenarios presented in the aforementioned cases demonstrates the problematic application of previous research towards the estimation of PMI. Studies that were discussed here are descriptive in nature and did not easily lend themselves towards an estimation of PMI for these cases.

Aquatic Depositions

The first case (Case 11) was in the fresh stage of decay and the second case (Case 12) was in the bloated stage. The third case (Case 13) had a postmortem interval of 2.5 months and was also in the bloated stage of decomposition. This last case was consistent with a decelerated rate of decay for aquatic environments (Rodriguez 1997).

The first case (Case 11) was fresh and had a PMI of one day, which is consistent with Bass' (1997) predictive model for outdoor surface remains. However, a PMI of one day does not provide much time to accrue decompositional changes. This case study was not very informative of taphonomic changes for aquatic environments. The second case (Case 12) had a PMI of two days and was within the bloated stage of decay, which is also consistent with Bass' model. Several of this case's taphonomic effects were also consistent with Bass' (1997) depiction of decomposition within the first week, namely: bloating, marbling, skin slippage, and the release of body fluids (assumed to be part of the decompositional gases that were noted around the body). The rapid onset of bloating may be due to the short postmortem interval during warm summer temperatures. However, there was not much information on Case 12 outside of the state of the remains. Also, a PMI of only one and two days do not provide much information on the variability of decay. Thus, Cases 11 and 12 were not very informative on taphonomic changes associated with aquatic Midwest environments.

The third case (Case 13) was a bloated corpse with an extended PMI of approximately two months. For this extended postmortem interval, Bass' (1997) model would predict an advanced level of decay. Yet the corpse was substantially well preserved for what might be expected of a surface deposition during the summer. The decelerated rate of decay described here is consistent with the literature for bodies decomposing in aquatic environments (Haglund and Sorg 2002b; Rodriguez 1997; Spitz 2006). It is also possible that clothing may have acted as a barrier to the body and retarded the decomposition of the body (Galloway 1997; Galloway *et al*. 1989; Komar 1998; Mann *et al*. 1990). This case (Case 13) was found to be fully clothed, whereas the other two cases were only mostly (50.0-75.0%) or moderately (<50.0%) clothed. However, clothing could have also contributed to an accelerated loss of soft tissue within this aquatic environment (Haglund 1993).

The descriptions of the cadavers found in aquatic environments suggest that they do resemble the intrinsic decomposition changes described by Bass (1997) for decomposition on ground surface. However, the small sample size and the narrow range of variability in decomposition for this sample make it difficult to make meaningful inferences on rates of decay and the PMI for aquatic locations. Additionally, the aquatic cases lacked information on the ambient environment and the position of the remains when discovered, which could have greatly improved the quality of this analysis.

<u>*Enclosed Depositions*</u>

Relationships between PMI, ADD and Decay Rate

The relationship between time, temperature and rate of decay have already been well established (*i.e*. Bass 1997; Clark *et al*. 1997; Galloway 1997; Galloway *et al.* 1989; Gill-King 1997; Higley and Haskell 2001; Haskell 2006; Komar 1997; Love and Marks

2001; Manhein 1997; Mann *et al.* 1990; Megyesi *et al*. 2005; Perper 2006; Rodriguez and Bass 1985; Vass 2001; Vass *et al*. 1992; Voss *et al*. 2008). Yet these relationships needed to be demonstrated using the thesis data to test whether: the retrospective data possessed variability in all three factors and were appropriate for taphonomic analysis, PMI and ADD are appropriate measures for the rate of decay, and decomposition rates for indoor Nebraska follow a different timeline than outdoor Tennessee.

Results showed that PMI and ADD shared a relationship with stages of decay, and that there were significant differences in PMI and ADD by stage of decay. Additionally, Bass' (1997) model for summer outdoor decay in Tennessee adequately accounted for the variation in decomposition among the Nebraskan sample. These relationships showed that the sample possessed variation in decomposition and was adequate for investigation of decay. Therefore, meaningful research on decomposition can and should be conducted with retrospective data.

These aforementioned results set the rational for performing *odds ratios* on individual taphonomic effects. Bass' (1997) stages of decay are composed of taphonomic indicators, which appear and disappear over time. The *odds ratios* demonstrated that marbling, bloating, green discoloration, mummification and brain liquefaction were all more likely to be present after the first week of the postmortem interval. Bass' (1997) model for outdoor surface decomposition places the presence of bloating and marbling within the first week of decay. While the indoor Nebraska and outdoor Tennessee results are not wholly incompatible, they do suggest a decelerated rate of early postmortem changes for remains located indoors. This decelerated rate of taphonomic change is consistent with the findings of Galloway and colleagues (1989), where bodies deposited in closed structures decayed more slowly during the initial phases of decomposition. Therefore, the results from the *odds ratios* implied variability in decay rates between indoor and outdoor environments, and were valuable in understanding when these taphonomic effects actually occurred for indoor depositions.

It was not known why Bass' (1997) model was reliable when applied to the indoor sample. The relationship between decay rates of outdoor Tennessee and indoor Nebraska could exist because indoor temperatures are often controlled and are more uniform so that there are rarely extreme temperature fluctuations. Therefore, it is plausible that cadavers within houses decomposed at comparable rates to those outdoor summer cases in Tennessee because of indoor control over temperature. However, this explanation could not be empirically verified for these data. Also, it should be noted that these results do not imply that the Tennessee model for estimation of the postmortem interval is widely applicable across the world. The indoor environment introduces a control for temperature that cannot be extended to other environments, particularly where there are extreme seasonal and daily temperature fluctuations. It is likely that the time ranges given by Bass would not be appropriate for cases of decomposition from other environments.

Temperature is the most important factor in the rate of decay (Clark *et al*. 1997; Gill-King 1997; Manhein 1997; Mann *et al.* 1990; Perper 2006). The results of this study corroborated the utility of accumulated degree days as a more appropriate measure for decompositional rate than time alone (Love and Marks 2001; Megyesi *et al*. 2005; Vass *et al.* 1992). The incorporation of temperature with time also makes ADD more universally relevant for predicting the postmortem interval. Temperature accumulation over time sets the tempo for decomposition. Therefore, future decomposition research should attempt to predict the accumulated degree days in replacement of or in addition to the postmortem interval.

Nonessential Variables Identified

It was of interest to identify what variables were related to the rate of decay. Several of the variables investigated failed to demonstrate a significant relationship with PMI or ADD. The intrinsic variables that did not reveal a relationship included: estimated BMI, age, stature, lividity, fluid stain, and the whether the organs were examinable. Burial factors that showed no relationship to rate of decay included: presence of a container, room of deposition within the home and the type of surface where the body was deposited. While many of these variables are commonly thought to influence the rate of decomposition, this relationship was not reflected in the analysis.

Age, stature, and estimated BMI did not show a relationship with PMI or ADD, although stature was correlated with the transformed Y (LogADD). Therefore, these intrinsic characteristics demonstrated no relationship to the rate of decay. Although livor mortis is characteristic of the early postmortem period (Clark *et al.* 1997; Perper 2006), the predictive power of lividity on ADD was never tested. This variable was eliminated due to its high prevalence among all stages of decay, which was interpreted as an error in data collection. Although fluid stain and examinable organs did not correlate with ADD, their relationship to decay has been well established within the literature (Bass 1997; Clark *et al.* 1997; Gill-King 1997; Perper 2006). While they are known results of decomposition, the analysis revealed that they were not the best predictors for the rate of decay.

The presence of a container and the surface of deposition have also previously been implicated as influential on the rate of decay (Mann *et al*. 1990). While this thesis did not identify these variables as influential, it is possible that limitations inherent to retrospective data skewed their relationships to PMI and ADD. For the surface of deposition, the specific material could not be discerned from the police and autopsy reports. In addition, there were two bodies that were still fresh after the first day of decomposition and both had decomposed on synthetic surfaces, such as carpet, bedding and a car seat. Although it is possible that these surfaces affected the rate of decay, there was not enough information to provide evidence for the trend specified in the literature (Mann *et al*. 1990).

For containers, the relationship may have been altered by the classification of vehicles as containers. Vehicles were not categorized separately because the sample sizes for containers and vehicles were too small to identify trends. Whereas containers are thought to slow the rate of decay, vehicle depositions are believed to experience an accelerated rate of decay due to the higher temperatures (Haskell 2006:170; Voss *et al*. 2008). This trend was supported by the data, where all three advanced cases that were only within their first week of decomposition were also located within vehicle containers. This suggested that vehicle deposition greatly accelerated the rate of human decay, which is consistent with the Voss *et al*. (2008) findings. Thus, the relationship between containers and the rate of decomposition may have been altered by the inclusion of vehicles as containers.

While clothing was not considered a surface or a container, clothing has also been implicated as a barrier that decelerates the rate of decay (Galloway 1997; Galloway *et al*. 1989; Komar 1998; Mann *et al*. 1990). However, that relationship was neither established nor invalidated here. The percentage of body surface covered by clothing was not significantly correlated with PMI or ADD but was correlated with the LogADD. The results from this study only showed that the surface of deposition and containers were not useful predictors for ADD. It was not possible to more thoroughly investigate the roles of containers, surfaces and clothing within this study. Future experimental research should focus on these variables.

Important Variables Identified

Table 5.1 lists all the variables that were identified as being important in the analysis of decomposition within enclosed environments. Marbling, mummified skin, the presence of decomposition odor, brain liquefaction and the use of air conditioning or heat were all selected for the predictive regression model. Therefore, these variables were identified as being the most important factors for prediction of decay within enclosed environments. All variables that were selected for the model showed significant correlations with the raw variable ADD. Although ADD were transformed to the

LogADD for the purpose of creating a predictive model, the transformation of the Y did not detract from the important information gained from this analysis.

It was of interest to identify environmental factors that influence the velocity of decay within enclosed environments. The use of AC/heat was one of two variables that accounted for the most variation within the model. While the use of AC/heat was not correlated with the transformed y (LogADD), it was significantly correlated with the untransformed y (ADD). Thus, it was considered and then selected for the model. Ultimately, this variable accounted for a significant portion of the variation within the model ($t=5.659, p=0.002$). The use of air conditioning and heat probably accounted for some of the disparity between indoor and outdoor temperatures, since outside temperatures were used to create the ADD. Although the seasons during decomposition were not selected for the model, they were significantly correlated with ADD and its transformation. Additionally, the results from the *odds ratio* demonstrated that decomposition is 1.5 times more likely to occur in the spring and summer than in the fall and winter. This was consistent with trends in the literature, where decay rates were accelerated in the summer in comparison to the winter (Bass 1997; Galloway 1997; Galloway *et al.* 1989; Komar 1997; Rodriguez and Bass 1983).

The *odds ratio* result also alluded to the problem with only predicting time, when temperature and moisture greatly affect the rate of decay (Mann et *al*. 1990). The greater likelihood of decomposition in the spring and summer also implied that climate affects the rate of decay within enclosed environments. Since seasons capture temporal variation of temperature into one variable (Bass 1997; Galloway *et al*. 1989; Galloway 1997;

Komar 1997), seasons could be used to strengthen the relationship between taphonomic factors and ADD. Seasons were an easy and practical way to approximate temperature during the PMI and should continue to be considered for future models.

Bass' (1997) stages heavily emphasize the actions of insects in soft tissue removal for outdoor decomposition. Since enclosed environments present more barriers for access to indoor remains, there is confusion as to whether insects greatly contribute towards indoor decay (Goff 1991; Haskell 2006; Schroeder *et al*. 2002). Similarly, while rare cases of animal scavenging within enclosed environments have been documented (Galloway *et al*. 1989; Perper 2006; Steadman and Worne 2007), their contribution towards decomposition has not previously been quantified.

The results indicated that animal scavenging did not greatly contribute toward indoor decomposition, as there was only one case of canine scavenging. Flies were the most prevalent necrophages, while beetles were not represented. These results supported the findings by Goff (1991), where the diversity of colonizing insect species is restricted within enclosed environments. Although Voss *et al*. (2008) witnessed a delayed insect colonization on bodies within vehicles, only 33.3% of remains in vehicles showed evidence of fly activity. Collectively, the presence of necrophagous activity shared a relationship with PMI, ADD and the LogADD and was originally selected for the model. It was manually removed because when it was included the models produced had a much lower adjusted R^2. Although necrophagous activity was limited in this sample, it clearly held an important relationship with the rate of decay, which is consistent with previous research (Rodriguez and Bass 1983; Mann *et al*. 1990; Bass 1997).

Based on these findings, necrophagous activities significantly influence the rate of decay when present, but animals and insects frequently cannot access enclosed remains. While it is possible that necrophagous activity (particularly beetles) was underreported in this sample, the persistence of bloating and the delayed onset of skeletonization may potentially result from the lack of necrophagous activity within enclosed settings. The frequency of indoor decomposition and the minimal role of necrophagous activity on enclosed remains underlined the need to generate context-specific standards for PMI estimation within enclosed environments.

The intrinsic characteristics selected for the predictive model were: decomposition odor, marbling, mummification of skin and liquefaction of the brain. Although correlations were identified among some of the taphonomic effects, multicollinearity was inherent to the nature of the data and the research question that was being investigated. Autolysis and putrefaction were at the root cause for most of the taphonomic effects that displayed multicollinearity and therefore correlations among them were unavoidable.

The presence of decomposition odors accounted for the most variation within the model. Since the brain has a high concentration of hydrolytic enzymes, brain liquefaction occurs rather quickly after death and represents an earlier postmortem change (Gill-King 1997:97). The release of odors and the discoloration of blood vessels are both putrefactive changes that occur early to intermediate in the decomposition process (Bass 1997; Clark *et al*. 1997; Gill-King 1997). Mummification is less likely to occur on indoor remains (Galloway 1997). When it does occur, it is a late taphonomic development in decomposition for enclosed settings (Galloway *et al*. 1983). Although these variables overlapped at times, the regression model has incorporated taphonomic changes that spanned across the spectrum of time and ADD represented by the data. Therefore, not only did this combination of variables account for the most variation, there is also a theoretical relationship to support the use of these variables for predicting the rate of decomposition.

There is still some question as to how important size is in prediction of ADD or rate of decay. Body size should be further investigated for relationships with taphonomic change, since body mass is lost during the decomposition process (Bass 1997; Galloway *et al*. 1989; Komar 1997; Rodriguez and Bass 1983; Roksandic 2002). In this study, estimated weight and BMI were not normal and transformations were unsuccessful so their predictive power for the rate of decay could not be explored. Yet the correlations for estimated weight with ADD and the LogADD implied that weight shares a relationship with the rate of decay. Future research is needed to empirically validate and quantify the relationship between body mass lost to decomposition and the PMI.

All the variables listed in 5.1 shared a relationship with the rate of decay, but to varying degrees. The variables selected for the model in the stepwise regression were implicated as the most important variables for decomposition within enclosed settings. Weight and the percent of the body covered by clothing merit further investigation to establish their relationships with taphonomic change. All other variables demonstrated a relationship with ADD that supports their consideration for future research. These variables are not new to decomposition research. Yet what is valuable in this thesis is that they were employed in a statistical model that not only predicts the rate of decay, but also produces a quantification of the standard error. Therefore, this model is a response to the growing concerns for sound research practices (National Research Council 2009) and will withstand the rigors of the judicial system by meeting the need for accuracy and validity of estimates (Christensen 2004; Christensen and Crowder 2009; Kimmerle and Jantz 2008; Ross and Kimmerle 2009).

Table 5.1—Important Variables for Predicting ADD.

Intrinsic	• Brain liquefaction*
	• Decomposition odors**
	• Marbling**
	• Mummified skin*
	• Weight
	• Rigor
	• Skin Slippage
	• Bloating
	• Green Discoloration
Extrinsic	• Seasons
	• Insect access
	• Necrophagous activity
Epidemiological	• Use of AC or heat**
	• % of body covered by clothing

* Represents variables selected as significant for the multiple linear regression model. Everything else was excluded.
** Represents variables that independently accounted for a significant portion of the variation in the multiple linear regression model.

Recommendations for Best Practice

Mann and colleagues (1990) assert that temperature is the most important factor in decompositional change over time, which has been corroborated by others (Clark *et al*. 1997; Gill-King 1997; Perper 2006). Additionally, Manhein (1997) has identified that forensic anthropologists involved in casework across the United States believe there is a need to improve the recording of climate for decomposition research. This thesis research and Megyesi *et al*. (2005) have shown that that local weather stations' climatological data were useful contributions toward the reconstruction of decay rates. Additionally, this research provides support for the use of ADD as a measure of decompositional change. For this reason, it is critical that future research focuses both on PMI days as well as ADD (Megyesi *et al*. 2005). Both should be reported and compared so that the published literature can contribute to the understanding of the disparity between these two variables. Additionally, research that reports both the postmortem interval and accumulated degree days becomes more pertinent for anthropologists engaged in death investigations. Those who utilize the methods can choose to employ the measure that is most applicable to the setting of the remains under examination.

A study conducted by Megyesi and colleagues (2005) created simple linear regression models that predict the log of PMI and the LogADD for bodies that decomposed between three to twelve months. They found that more variation was accounted for with the model that predicted the LogADD (2005:623), which supports the presentation of both measures as well as the placement of emphasis on predicting accumulated temperature rather than time. The creation of more research that uses ADD as an alternative to but in conjunction with PMI days can make the methods more widely applicable and also provide opportunities for others to test them in novel environments.

The Megyesi *et al*. (2005) study only used intrinsic taphonomic effects as predictive variables, as have other published research (Galloway *et al*. 1989; Bass 1997; Clark *et al*. 1997; Gill-King 1997). This thesis also resulted in a model that prioritized intrinsic decomposition changes. It is paramount that future studies incorporate extrinsic and burial factors in addition to intrinsic changes into multivariate statistical analyses for the prediction of ADD and PMI.

Epidemiological variables were often found to have high correlations with ADD but low correlations with the intrinsic taphonomic effects. Inclusion of extrinsic and epidemiological variables in conjunction with fewer intrinsic variables could help avoid issues of multicollinearity. Further, inclusion of epidemiological and extrinsic variables puts more emphasis on the dynamic processes that produce taphonomic effects, an area that needs to be further developed (Gifford 1982:493).

Therefore, if epidemiological factors could be identified and found to correlate with PMI or ADD, they could greatly contribute to the construction of a robust predictive model. The use of extrinsic and epidemiological influences in conjunction with indicators of decay could produce excellent statistical models for estimating the accumulated temperature since death. This requires further diligent retrospective research to identify more variables and further test those listed here for their relationship to decompositional changes and ADD. More testing is also needed for the production of known error rates.

Since the rate of decay is determined by a combination of many factors, future research should continue to focus on the creation of predictive models that are environmentally specific (Galloway 1997; Galloway *et al*. 1989; Grupe 2007; Komar 1998; Lyman 1994; Mann *et al.* 1990; Megyesi *et al.* 2005; Rodriguez and Bass 1985; Roksandic 2002; Sorg and Haglund 2002; Voss *et al*. 2008). The variables listed in Table 5.1 should continue to be tested in future research among diverse locations. This list can and should be further investigated and thoroughly revised to reflect the best combination of variables for every tested environment.

More focus on the multitude of factors that affect rates of taphonomic change during the postmortem interval can help forensic anthropologists move away from stage data and towards robust multivariate analyses. As Christensen and Crowder note, "quantitative data is based upon qualitative judgments, and all qualitative data can be described and manipulated numerically (2009:1213-1214)." Multivariate analyses can aid in making theoretical generalizations in taphonomic and by extension forensic anthropology research (Lyman 1994), and are more likely to meet the *Daubert* standard. An anthropological framework that considers epidemiological, extrinsic and intrinsic factors is well suited to a multivariate approach and embraces the intricate and dynamic relationships among the human behaviors associated with a death event, the body, and it's extrinsic and epidemiological surroundings. In essence, this framework allows the anthropologist to contextualize the taphonomic findings within the broader conditions that defined a death event.

On a more practical note, multivariate models that embrace these three domains can avoid issues in multicollinearity, put emphasis on the dynamics of decompositional change, and comprehensively address death and decomposition within an anthropological framework. The identification and utilization of variables that are most important in affecting the rate of decomposition will produce sound research models that meet the criteria for relevance and reliability established in *Daubert*, *Joiner* and *Kumho* (refer to Christensen 2004; Christensen and Crowder 2009; Grivas and Komar 2008). Further development of the anthropological model employed in this thesis will move this body of research beyond the particularized and descriptive approach and towards more robust analyses with meaningful results both to the anthropological and legal communities.

Literature Cited

Adams, Vernard I. with Mark A. Flomenbaum and Charles S. Hirsch
2006 Trauma and Disease. *In* Spitz and Fisher's Medicolegal Investigation of Death. Werner Spitz and Daniel Spitz, eds. Pp.436-459. Springfield, Illinois: Charles C Thomas.

Alberts, Bruce with Dennis Bray, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts and Peter Walter
1998 Essential Cell Biology: An Introduction to the Molecular Biology of the Cell. New York and London: Garland Publishing, Inc.

Bass, William M.
1997 Outdoor Decomposition Rates in Tennessee. *In:* Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 181-186. New York: CRC Press.

Behrensmeyer, Anna K. and Andrew P. Hill, eds.
1980a Preface. *In* Fossils in the Making: Vertebrate Taphonomy and Paleoecology. Pp. xi-xii. Chicago: University of Chicago Press.

1980b Introduction. *In* Fossils in the Making: Vertebrate Taphonomy and Paleoecology. Pp. 1-2. Chicago: University of Chicago Press.

Buikstra, Jane E. and Douglas H. Ubelaker (eds)
1994 Standards for Data Collection from Human Skeletal Remains. Proceedings of a Seminar at the Field Museum of Natural History. Arkansas Archaeological Survey Research Series No 44, Arkansas

Butera, S. M. with F. Postma, C. Wells, and E. H. Kimmerle
2007 Estimating Time Since Death Using Soil Chemistry of Burial Silhouettes. Poster presented at the 4th Annual Forensic Sciences Symposium, Nebraska Institute of Forensic Sciences, Lincoln, Nebraska.

Carter, David O. with David Yellowlees and Mark Tibbett
2007 Cadaver Decomposition in Terrestrial Ecosystems. Naturwissenschaften 94:12-24.

Christensen, Angi M.
2005 Testing the Reliability of Frontal Sinuses in Positive Identification. Journal of Forensic Sciences 50(1):18-22.

2004 The Impact of *Daubert*: Implications for Testimony and Research in Forensic Anthropology (and the Use of Frontal Sinuses in Personal Identification). Journal of Forensic Sciences 49(3):427-430.

Christensen, Angi M. and Christian M. Crowder
2009 Evidentiary Standards for Forensic Anthropology. Journal of Forensic Sciences 54(6):1211-1216.

Clark, Michael A. with Michael B. Worrell and John E. Pless
1997 Postmortem Changes in Soft Tissues. *In:* Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 151-164. New York: CRC Press.

Dirkmaat, Dennis C. and J.M. Adovasio
1997 The Role of Archaeology in the Recovery and Interpretation of Human Remains from an Outdoor Forensic Setting. *In:* Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 39-64. New York: CRC Press.

Fiedler, Sabine and Matthias Graw
2003 Decomposition of Buried Corpses, with Special Reference to the Formation of Adipocere. Naturwissenschaften 90:291-300.

Galloway, Allison
1997 The Process of Decomposition: a Model from the Arizona Sonoran Desert. *In*: Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 139-150. New York: CRC Press.

Galloway, Allison with W.H. Birkby, A.M. Jones, T.E. Henry and B.O. Parks
1989 Decay Rates of Human Remains in an Arid Environment. Journal of Forensic Sciences 34:607-616.

Gifford, Diane P.
1982 Taphonomy and Paleoecology: A Critical Review of Archaeology's Sister Disciplines. *In* Advances in Archaeological Method and Theory. Michael B. Schiffer, ed. Pp. 465-538. New York: Academic Press, Inc.

Gill-King, Harrell
1997 Chemical and Ultrastructural Aspects of Decomposition. *In*: Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 93-108. New York: CRC Press.

Goff, M.L.
1991 Comparison with Insect Species Associated with Decomposing Remains Recovered Inside Dwellings and Outdoors on the Island of Oahu, Hawaii. Journal of Forensic Sciences 36:748-753.

Gould, Stephen J.
1979 Agassiz's Marginalia in Lyell's Principles, or the Perils of Uniformity and the Ambiguity of Heroes. Studies in History of Biology 3:119-138.

1965 Is Uniformitarianism Necessary? American Journal of Science 236:223-228.

Grivas, Christopher R. and Debra A. Komar
2008 *Kumho*, *Daubert*, and the Nature of Scientific Inquiry: Implications for Forensic Anthropology. Journal of Forensic Sciences 53(4):771-776.

Grupe, Gisela
2007 Taphonomic and Diagenetic Processes. *In* Handbook of Paleoanthropology, vol. 1: Principles, Methods and Approaches. Winfried Henke and Ian Tattersall, eds. Pp. 241-259. New York: Springer Berlin Heidelberg.

Haglund, W.D., ed.
1997a Dogs and Coyotes: Postmortem Involvement with Human Remains. *In*: Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 367-381. New York: CRC Press.

1997b Rodents and Human Remains. *In:* Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 405-414. New York: CRC Press.

1993 Disappearance of Soft Tissue and the Disarticulation of Human Remains from Aqueous Environments. Journal of Forensic Sciences 38(4):806-815.

Haglund, W.D. and M.H. Sorg, ed.s
2002a Advances in Forensic Taphonomy. Method, Theory, and Archaeological Perspectives. New York: CRC Press.

2002b Human Remains in Water Environments. *In* Advances in Forensic Taphonomy, William Haglund and Marcella Sorg, eds. Pp.201-218. New York: CRC Press.

1997a Forensic Taphonomy. The Postmortem Fate of Human Remains. New York: CRC Press.

1997b Introduction to Forensic Taphonomy. *In*: Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 1-9. New York: CRC Press.

1997c Method and Theory of Forensic Taphonomy Research. *In*: Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 13-26. New York: CRC Press.

Haskell, Neal
2006 Forensic Entomology. *In* Spitz and Fisher's Medicolegal Investigation of Death. Werner Spitz and Daniel Spitz, eds. Pp.149-173. Springfield, Illinois: Charles C Thomas.

Henke, Winfried, ed.
2007 Historical Overview of Paleoanthropological Research. *In* Handbook of Paleoanthropology, vol. 1: Principles, Methods and Approaches. Winfried Henke and Ian Tattersall, eds. Pp. 1-56. New York: Springer Berlin Heidelberg.

Henke, Winfried and Ian Tattersall, eds.
2007 Handbook of Paleoanthropology, vol. 1: Principles, Methods, and Approaches. New York: Springer Berlin Heidelberg.

Higley, Leon G. and Neal H. Haskell
2001 Insect Development and Forensic Entomology. *In* Forensic Entomology: the Utility of Arthropods in Legal Investigations. Jason H. Byrd and James L. Castner, eds. Pp.287-302. Boca Raton: CRC Press.

Junqueira, Luiz C. and José Carneiro
2005 Basic Histology. New York: McGraw-Hill.

Kimmerle, Erin H. and José Pablo Baraybar
2008 Skeletal Trauma: Identification of Injuries Resulting from Human Rights Abuse and Armed Conflict. Boca Raton: CRC Press.

Kimmerle, Erin H. with Anthony Falsetti and Ann H. Ross
2009 Immigrants, Undocumented Workers, Runaways, Transients and the Homeless: Towards Contextual Identification Among Unidentified Decedents. Forensic Science Policy and Management 1:178-186.

Kimmerle, Erin H. and Richard L. Jantz
2008 Variation as Evidence: Introduction to a Symposium on International Human Identification. Journal of Forensic Sciences 53(3):521-523.

Komar, Debra A.
1997 Decay Rates in a Cold Climate Region: A Review of Cases Involving Advanced Decomposition from the Medical Examiner's Office in Edmonton, Alberta. Journal of Forensic Sciences 43:57-61.

Konigsberg, Lyle W. with Nicholas P. Herrmann, Daniel J. Wescott and Erin H. Kim
2008 Estimation and Evidence in Forensic Anthropology: Age at Death. Journal of Forensic Sciences 53(3):541-557.

Konigsberg, Lyle W. with Ann H. Ross and William L. Jungers
2006 Estimation and Evidence in Forensic Anthropology: Determining Stature. *In* Forensic Anthropology and Medicine: Complementary Sciences From Recovery to Cause of Death. Aurore Schmitte, Eugenia Cunha and João Pinheiro, ed.s. Pp.317-331. Totowa: Humana Press Inc.

Krebs, Charles J.
1972 Ecology: The Experimental Analysis of Distribution and Abundance. New York: Harper and Row.

Love, Jennifer C. and Murray K. Marks
2003 Taphonomy and Time: Estimating the Postmortem Interval. *In* Hard Evidence: Case Studies in Forensic Anthropology. Dawnie W. Steadman, ed. Pp.160-175. Upper Saddle River: Pearson Education, Inc.

Lyman, R. Lee
2002 Foreword. *In* Advances in Forensic Taphonomy, William Haglund and Marcella Sorg, eds. Pp.xix-xxi. New York: CRC Press.

1994 Vertebrate Taphonomy. Cambridge: Cambridge University Press.

Manhein, Mary H.
1997 Decomposition Rates of Deliberate Burials: A Case Study of Preservation. *In* Forensic Taphonomy: The Postmortem Fate of Human Remains. Haglund, W.D., Sorg, M.H., eds. Pp. 469-481. New York: CRC Press.

Mann, R.W. with William M. Bass and Lee Meadows
1990 Time Since Death and Decomposition of the Human Body: Variables and Observation in Case and Experimental Field Studies. Journal of Forensic Sciences, 35:103-111.

Megyesi, Mary S. with Stephen P. Nawrocki and Neal H. Haskell
2005 Using Accumulated Degree-Days to Estimate the Postmortem Interval from Decomposed Human Remains. Journal of Forensic Sciences, 50 (3):618-626.

Mellen, Paul F. M. with Mark A. Lowry and Mark S. Micozzi
1993 Experimental Observations on Adipocere Formation. Journal of Forensic Sciences 38(1):91-93.

Micozzi, Marc
1986 Experimental Study of Postmortem Change Under field Conditions: Effects of Freezing, Thawing, and Mechanical Injury. Journal of Forensic Sciences, 31(3):953-961.

Mielke, James H. with Lyle W. Konigsberg and John H. Relethford
2006 Human Biological Variation. New York: Oxford University Press.

Morten, Robert J. and Wayne D. Lord
2002 Detection and Recovery of Abducted and Murdered Children: Behavioral and Taphonomic Influences. *In* Advances in Forensic Taphonomy, William Haglund and Marcella Sorg, eds. Pp.151-171. New York: CRC Press.

National Climatic Data Center
2008[2009] What is NCDC? Electronic document, http://www.ncdc.noaa.gov/oa/about/whatisncdc.html, accessed August 25, 2009.

National Research Council
2009 Strengthening Forensic Science in the United States: A Path Forward. Research Report, 228091. Washington, DC: National Academy Press, National Academy of Sciences.

Nebraska Institute of Forensic Sciences
2003 Vision Statement. Electronic document, http://www.nebraskaforensic.com/Home.htm, accessed May 5, 2008.

Nordby, Jon
2002 Is Forensic Taphonomy Scientific? *In* Advances in Forensic Taphonomy, William Haglund and Marcella Sorg, eds. Pp.31-42. New York: CRC Press.

Perper, Joshua
2006 Time of Death and Changes After Death. Anatomical Considerations. *In* Spitz and Fisher's Medicolegal Investigation of Death. Werner Spitz and Daniel Spitz, eds. Pp.87-127. Springfield, Illinois: Charles C Thomas.

Rodriguez, William C.
1997 Decomposition of buried and Submerged Bodies. *In* Forensic Taphonomy: The Postmortem Fate of Human Remains. Haglund, W.D., Sorg, M.H., eds. Pp. 459-467. New York: CRC Press.

Rodriguez, William and William Bass
1983 Insect Activity and its Relationship to Decay Rates of Human Cadavers in East Tennessee. Journal of Forensic Sciences, 28(2):423-432.

1985 Decomposition of Buried Bodies and Methods that May Aid in Their Location. Journal of Forensic Sciences, 30(3):836-852.

Rogers, Tracy L.
2005 Determining the Sex of Human Remains Through Cranial Morphology. Journal of Forensic Sciences, 50(3):493-300.

Rogers, Tracy L. and Travis T. Allard
2004 Expert Testimony and Positive Identification of Human Remains Through Cranial Suture Patterns. Journal of Forensic Sciences 49(2):203-207.

Roksandic, Mirjana
2002 Position of Skeletal Remains as a Key to Understanding Mortuary Behavior. *In* Advances in Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 99-117. New York: CRC Press.

Ross, Ann H. and Erin H. Kimmerle
2009 Contribution of Quantitative Methods in Forensic Anthropology: A New Era. *In* Handbook of Forensic Anthropology and Archaeology. Soren Blau and Douglas H. Ubelaker, eds. Pp.479-489. Walnut Creek: Left Coast Press, Inc.

Saul, Julie M. and Frank P. Saul
2002 Forensics, Archaeology, and Taphonomy: The Symbiotic Relationship. *In* Advances in Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 71-97. New York: CRC Press.

Schroeder, H. with H. Klotzbach , L. Oesterhelweg and K. Puschel
2002 Larder Beetles (Coleoptera, Dermestidae) as an Accelerating Factor for Decomposition of a Human Corpse. Forensic Science International, 127(3):231-236.

Scott, Douglas D. and Melissa Connor
1997 Context Delicti: Archaeological Context in Forensic Work. *In* Advances in Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 27-38. New York: CRC Press.

Skinner, Mark with Djordje Alempijevic and Marija Djuric-Srejic
2003 Guidelines for International Forensic Bio-archaeology Monitors of Mass Grave Exhumations. Forensic Science International 134:81-92.

Sorg, M.H. and W.D. Haglund, ed.s
2002 Advancing Forensic Taphonomy: Purpose, Theory, and Practice. *In* Advances in Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 3-29. New York: CRC Press.

Spitz, Daniel J., ed.
2006 Investigation of Bodies in Water. *In* Spitz and Fisher's Medicolegal Investigation of Death. Werner Spitz and Daniel Spitz, eds. Pp. 846-881. Springfield, Illinois: Charles C Thomas.

Spitz, Werner, and Daniel Spitz, ed.s
2006 Spitz and Fisher's Medicolegal Investigation of Death. Werner Spitz and Daniel Spitz, eds. Springfield, Illinois: Charles C Thomas.

Steadman, Dawnie and Heather Worne
2007 Canine Scavenging of Human Remains in an Indoor Setting. Forensic Science International, 173:78-82.

Steadman, Dawnie Wolfe with Bradley J. Adams and Lyle W. Konigsberg
2006 Statistical Basis for Positive Identification in Forensic Anthropology. American Journal of Physical Anthropology 131:15-26.

Ubelaker, Douglas
1997 Taphonomic Applications in Forensic Anthropology. *In* Forensic Taphonomy. Haglund, W.D., Sorg, M.H., eds. Pp. 77-90. New York: CRC Press.

Vass, Arpad
2001 Beyond the Grave—Understanding Human Decomposition. Microbiology Today, 28:190-192.

Vass, Arpad, with William Bass, Jeffery Wolt, John Foss and John Ammons
1992 Time Since Death Determinations of Human Cadavers Using Soil Solution. Journal of Forensic Sciences, 37(5):1236-1253.

Voss, Sasha, with Shari Forbes and Ian Dadour
2008 Decomposition and Insect Succession on Cadavers Inside a Vehicle Environment. Forensic Science, Medicine, and Pathology, 4:22-32.

Appendices

Appendix A: Data Collection Protocol

USF FORENSIC ANTHROPOLOGY AND BIOARCHAEOLOGICAL SCIENCES LABORATORY (FABAS)
PROTOCOL FOR DECOMPOSITION RESEARCH
(Current and Updated Version Located on USF Intranet)
Last Revised: 14 June 2008
Citation: BFA Protocol for Decomposition Research of Human Remains in Varied Environments (EH Kimmerle. University of South Florida)

Research Collaborators:
Melissa Pope, MA Student, Department of Anthropology
Nebraska Institute of Forensic Sciences, Inc.

Introduction:
Data is collected for individuals who have died in enclosed environments and in outdoor environments and who remained there long enough to allow some decompositional changes.

DECOMPOSITION RATES (Adapted from Bass 1997:183-184)
BASED ON CHARACTERISTICS, CHOOSE WHATEVER PHASE <u>BEST</u> APPLIES.

<u>Fresh</u>

1. Egg masses will be white and may look like fine sawdust.
2. Veins under the skin may be turning blue or dark green (marbling).
3. Some body fluids may be seen around the nose and mouth.

<u>Early or Bloated</u>

1. Maggots have hatched and are active in the face.
2. Lips may be distended because of the maggot mass under the skin.
3. Skin around the eyes and nose is eaten away exposing bone
4. Beatles appear as a part of the sequence of carrion insect activity.
5. Skin slippage on the body is beginning.
6. Hair is beginning to slip from scalp.
7. Veins are prominent under the skin and are dark blue or dark green.
8. The odor of decay is present.
9. Body fluids may be flowing from the nose, mouth, and rectum.

Appendix A: (Continued)

10. Abdominal areas may be bloated.
11. Molds of various colors begin to appear on the body.
12. Mammalian carnivores may be active and will greatly speed up the decrease of soft tissue by eating the decaying tissue as well as bone.
13. Body fluids (volatile fatty acids) may have killed the vegetation immediately around the body.

Advanced or Decay

1. Maggot activity is much less and beetles are present on and around the decaying body.
2. Bloating is past and the body is in the decay phase.
3. If in the spring, birds may be using hair that has slipped from the scalp to build nests.
4. If the body has been covered most of the bones will be exposed where the soft tissue has decayed away.
5. If the body was not covered, the skin between the skeleton and the sunlight will be intact to protect the maggots from the sun. It will now be getting dry and leathery. If the body lies on its back the dry skin will be holding the ribs together.
6. Mammalian carnivores may be carrying off limb and even the skull.
7. Molds (of various colors) have spread over the soft tissue and on the ones. The area around the body may be stained dark and the body may appear to have been burned. This is from the volatile fatty acids that have leached out of the body during the decay process.
8. If the body decayed on an incline, these volatile fatty acids will kill the vegetation as it flows from the body.
9. Adipocere may appear on a body decaying in a moist environment. If in the water, the adipocere will first be seen in the area from about 2 inches above to 2 inches below the water line.

Dry; Mummified or Skeletonized

1. Bleaching of the skeleton has occurred from the sunlight.
2. The portions of the skeleton in the shade may have moss or green algae growing on them.
3. Rodent gnawing may be present along the crest or edges of bones (the eye orbits in the skull, the linea aspera of the femur, etc.).
4. Mice may be using the skull as a nest.
5. Wasps may build a nest in the skull if the skull was dry by late March or early April during the nest-building period.

Appendix A: (Continued)

BONE WEATHERING STAGES (from Buikstra and Ubelaker 1994:98)
(For remains that are skeletonized) **Choose the stage that best describes the remains.**
Stage 0: Bone surface shows no signs of cracking of flaking due to weathering.
Stage 1: Bone shows cracking, normally parallel to the fiber structure (e.g., longitudinal in long bones). Articular surfaces may show mosaic cracking.
Stage 2: Outermost concentric thin layers of bone show flaking, usually associated with cracks, in that the bone edges along the cracks tend to separate and flake first. Long thin flakes, with one or more sides still attached to the bone, are common in the initial part of Stage 2. Deeper and more extensive flaking follows, until most of the outermost bone is gone. Crack edges are usually angular in cross section.
Stage 3: Bone surface is characterized by patches of rough, homogeneously weathered compact bone, resulting in fibrous texture. In these patches, all the external, concentric layers of bone have been removed. Gradually the patches extend to cover the entire bone surface. Weathering does not penetrate deeper than 1.0-1.5mm at this stage, and bone fibers are still firmly attached to each other. Crack edges usually are rounded in cross section.
Stage 4: The bone surface is coarsely fibrous and rough in texture; large and small splinters occur and may be loose enough to fall away from the bone if it is moved. Weathering penetrates into inner cavities. Cracks are open and have splintered or rounded edges.
Stage 5: Bone is falling apart, with large splinters. Bone easily broken by moving. Original bone shape may be difficult to determine. Cancellous bone usually exposed, when present, and may outlast all races of the former more compact, outer parts of the bones.

Appendix A: (Continued)

DATE AND RECORDER:
POLICE AGENCY:
POLICE REPORT NO.:
AUTOPSY NO.:
DATE OF INCIDENT (specify time range):
DATE FOUND:
DATE/YEAR OF POLICE REPORT:

DEMOGRAPHIC INFORMATION OF DECEDENT:

OBS. 01: Sex 1=Male 2=Female

OBS. 02: Age (years)

OBS. 03: Ancestry:

1=Caucasian	4=Hispanic	6=Other (list)
2=African-American	5=American-Indian	99=Unknown
3=Asian		

OBS. 04: Was the person obese/overweight? 0=no 1=yes
99=unknown

DEATH EVENT:
OBS. 05: Manner of death
1=Homicide
2=Suicide
3=Accident
4=Natural
5=Undetermined

OBS. 06: Cause of death (list):

OBS. 07: Is the time of death known? 0=no 1=Yes
99=Unknown

OBS. 08: What date and time did the person die or when was the person last known/seen to be alive? (specify, add any pertinent details)

OBS. 09: When was the body found/recovered? (list date and time if possible)

Appendix A: (Continued)

OBS. 10: Who found the body?

0=friend	1=spouse	2=neighbor	3=police
4=stranger	5=other (list)	99=unknown	

OBS. 11: What is the location of where the person died and where the body was found (Provide address if possible. At-least provide city).

PERIMORTEM INJURY

OBS. 12: Were there injuries on the body? 0=No 1=Yes
99=Unknown

OBS. 13: If yes, approximately how many? (list)

OBS. 14: Location of injuries (on body) (list all that apply):

1=Head	4=Abdomen	7=Back
99=N/A		
2=Neck	5=Upper Extremity	8=Combination (list)
3=Thorax	6=Lower Extremity	9=Other

OBS. 15: Nature of Injury- Mechanism/Cause of Death:

1=Single GSW	4=SFT	6=Other (list and describe)
2=Multiple GSW	5=Strangulation	7=Unknown
99=N/A		

OBS. 16: Weapon:

1=handgun	5=Blunt (list specific)	99=Unknown/NA
2=Shotgun	6=Ligature (list specific)	
3=Rifle	7=Manual strangulation	
4=Sharp (list specific)	8=Other (list)	

BURIAL FACTORS

OBS. 17: Context of burial location:

1=Outdoor surface location
2=Sub-surface Burial (list depth)
3=Dismemberment
4=Water (list type of body of water, i.e., river, bay)
5=Burning/ fire or cremation
6=Indoor location

Appendix A: (Continued)

OBS. 18: Environment where body was recovered:

1=Public space 2=Private residence 3=Along roadside
4=Wooded area/field 5=Abandoned structure 6=Railroad tracks
7=Other (list): 99=Unknown

OBS. 19: What was the sun exposure where the body was recovered?

1=Sunny 2=Shady 3=mixed 99=unknown

OBS. 20: If body was recovered in a home or other indoor environment, what room was the body located in?

1=basement 2=bedroom 3=bathroom 4=kitchen

5=living room 6=attic 7=other (list) 99=Unknown

OBS. 21: Container:

0=none 1=blanket 2=shower curtain
3=carpet 4=trash bin/ dumpster 5=other (list)
99=unknown or N/A

OBS. 22: Surface that the body was laying on:

1=dirt 2=rocks 3=carpet 4=hardwood floors 5=tile
6=linoleum 7=submerged 8=other (list)
99=unknown

OBS. 23: Was the victim wearing clothing? 0=No 1=Yes
99=Unknown

OBS. 24: What kind of materials did the clothing consist of? (For each type of material, note what type of garment it was and what state of preservation it was in).

1=cotton 2=synthetic(list if possible) 3=animal (silk or wool)
4=other(list) 99=unknown

OBS. 25: Approximately how much did the clothing cover the body?

1=Minimally covered (less than 25%) 2=Moderately covered (less than 50%) 3=Mostly covered (50-75%) 4=Fully covered (more than 75%)
99=N/A or unknown

Appendix A: (Continued)

OBS. 26: What was the position of the body?

1=ventral surface in contact with floor
2=dorsal surface in contact with floor
3=lying on the body's side (laterally)
4=semiflexed or flexed
5=other or combination (list and describe)
99=unknown

OBS. 27: How complete are the skeletonized, mummified or scavenged remains?

1=≤25% 2=≈50% 3=≥75% 4=≈100% 99=Unknown

SCAVENGING ACTIVITY

OBS. 28: Was there post-mortem modification to the body? If human, describe.

0=No 1=Yes 99=Unknown
(This may include animal, insect or human activity).

OBS. 29: Was the body moved following the death event? 0=No 1=Yes 99=Unknown

OBS. 30: Evidence of scavenger activity? 0=No 1=Yes 99=Unknown

OBS. 31: If yes, what type of scavenger? (list all that apply).

1=canid 2=feline 3=ant 4=fly 5=roach
6=water creatures 7=combination (list) 99=unknown

OBS. 32: If yes, list species, describe pattern and extent of scavenging. (list)

OBS. 33: If insect activity was present, describe what species were present and the most advanced stages of development. (list) (Specify the extent of tissue loss due to scavenging).

OBS. 34: If larvae were found near the body, where were they found (ie- under carpet), and how many rooms had they occupied? (list) (be as specific as possible).

DECOMPOSITION STAGE DATA

OBS. 35: According to the stages outline by Bass (noted above), what stage BEST describes the condition of the human remains?

1=Fresh
2=Early or Bloated
3=Advanced or Decay
4=Skeletonized or Only Mummified Tissues
5=Bone Breakdown
99=Unknown

OBS. 36: Rigor: 0=Absent 1=Present 99=Unknown or NA

Appendix A: (Continued)

OBS. 37: Lividity: 0=Absent 1=Present 99=Unknown or NA

OBS.38: Skin Slippage:
0=Absent 1=Present 99=Unknown or NA

OBS.39: Postmortem Bullae:
0=Absent 1=Present 99=Unknown or NA

OBS.40: Marbling: 0=Absent 1=Present 99=Unknown or NA

OBS.41: Bloating: 0=Absent 1=Present 99=Unknown or NA

OBS. 42: Green Discoloration:
0=Absent 1=Present 99=Unknown or NA

OBS.43: Purge fluid (from mouth of nose):
0=Absent 1=Present 99=Unknown or NA

OBS.44: Mummified Skin:
0=Absent 1=Present 99=Unknown or NA

OBS.45: Adipocere: 0=Absent 1=Present 99=Unknown or NA

OBS.46: Decomposition Smell:
0=Absent 1=Present 99=Unknown or NA

OBS.47: Mold growth on the body:
0=Absent 1=Present 99=Unknown or NA

OBS.48: Postmortem blood clotting:
0=Absent 1=Present 99=Unknown or NA

OBS.49: Skeletonization:
0=None 1=≤25% 2=≈50% 3=≥75% 4=≈100%

OBS. 50: For skeletonized remains, what taphonomic stage best describes the remains?
Stage 0 Stage 1 Stage 2 Stage 3
Stage 4 Stage 5 99=N/A

Appendix A: (Continued)

OBS.51: If any portions of the body are skeletonized or mummified, list/describe what portions of the body. If skeletonized, describe presence/absence of soft tissue (ligaments).

TEMPERATURE DATA:
OBS. 52: Was the temperature at the time of death known? (LIST; be as specific as possible) 0=no 1=yes

OBS. 53: If NO, then what was the average, high, and low temperatures for that particular day? (Area specific: may have to go back to this with local weather data).

OBS. 54: What was the forecast when discovered (if known)? (Describe)
1=Sunny 2=Cloudy 3=Rainy 4=Snow/freeze
5=Shaded 6=Enclosed 99=Unknown

OBS. 55: List the date of last seen/death event (specify) and the date of discovery, and the interval.

OBS. 56: What seasons have occurred from the time of death to when the body was discovered?
1=Summer 2=Fall 3=Winter 4=Spring
5=Combination (list) 99=Unknown

OBS. 57: If the body was found in a sheltered or protected environment, what were some factors that may have modified the body's exposure to outdoor temperature/exposure? (list anything mentioned in the report)

INDOOR FACTORS (If the body was found in a sheltered environment):
OBS. 58: Were the windows closed? 0=No 1=Yes
99=Unknown

OBS. 59: Was the AC/Heat turned on? (specify heat or AC)
0=No 1=Yes 99=Unknown

OBS. 60: If YES, at what temperature was the thermostat set? (if they had a thermostat; list)

OBS. 61: If YES, what type of device was used?
1=central heat and air 2=window unit AC 3=electrical heater
4=other (specify) 99=Unknown

OBS. 62: If known, what temperature was the indoor environment when the body was found? (List) (Actual temperature and thermostat setting may be different).

OBS. 63: Were there any barriers blocking the skin from air exposure (i.e., blankets)? If Yes, List/Describe.

0=No 1=Yes 99=Unknown

OBS. 64: Comments (circumstances, description of the body and/or scene, what information was used to establish time since death, any other factors from reports that may be important).