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Qualifying and Quantifying the Rate of Decomposition in the Delaware River Valley Region

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Qualifying and Quantifying the Rate of Decomposition in the Delaware River Valley Region

Abstract

Human decompositional changes and the post-mortem interval (PMI) required to produce those effects have been demonstrated to vary tremendously based on environmental conditions specific to the region in which decomposition is taking place. Studies to that effect have been conducted in select areas throughout the country, but have yet to be undertaken in southeastern Pennsylvania, New Jersey, and Delaware. Given the hypothesis regarding regional differences in the rate of decay, this study set out to assess the decomposition process as it applies to the Delaware River Valley (DRV) region and to provide formulas from which to estimate time since death. The dearth of studies in this area, highlighted the need for region-specific standards, increased the accuracy of time since death estimates, and improved quantitative methods. To this end, a retroactive approach was taken in which cases from the Delaware Office of the Chief Medical Examiner with a known "date last seen" and "date recovered" were compiled. Using these cases, a qualitative analysis was conducted examining the specific decompositional changes which occur in various contexts. Quantitatively, a linear regression analysis was employed to determine if accumulated degree days (ADD) or PMI explained more of the variation in decomposition. To complement this work, a multivariate regression analysis was conducted to identify key covariates and assess their impact on the rate of decay. Lastly, to validate region-specific standards, the DRV models were compared to those presented in Megyesi et al. (2005). For this validation process, a specific progression to decomposition in the DRV was identified and total body score (TBS) systems for both outdoor and indoor cases, and aquatic depositions, were developed. ADD and TBS were determined to be central components in modeling decay. In addition, outdoor cases were demonstrated to decompose fastest. Finally, the DRV model explained more of the variation in decomposition and more accurately estimated ADD than that of Megyesi et al. (2005). In total, a set of time since death estimation formulas applicable to indoor, outdoor, and aquatic contexts were produced, and region-specific standards best-suited to estimating time since death in the Delaware River Valley were developed.

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QUALIFYING AND QUANTIFYING THE RATE OF DECOMPOSITION IN THE DELAWARE RIVER VALLEY REGION

Sergio C. Guerra

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Dedication

To my loving wife,
who has constantly supported me, cared for me, and has always been by my side.
I love you forever and ever, babe.

To my wonderful parents,
who have given everything to provide my family with a better life,
and have taught me what hard work and love is.

To my sister,
for believing in me and constantly having my back.

To my Godfather and Godmother,
for all that you have done to teach me, guide me, and shape me into the man I am today.

To the MOD,
who have always been there to pick me up, dust me off, and make me one of their own.

To my Grandmother and Grandfather,
for teaching me what true courage, honor, and unconditional love is.

A special place will always be reserved in my heart for each and every one of you.
Thank you and I love you all.

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ABSTRACT

QUALIFYING AND QUANTIFYING THE RATE OF DECOMPOSITION IN THE DELAWARE RIVER VALLEY REGION

Sergio C. Guerra

Robert Schuyler, PhD

Human decompositional changes and the post-mortem interval (PMI) required to produce those effects have been demonstrated to vary tremendously based on environmental conditions specific to the region in which decomposition is taking place. Studies to that effect have been conducted in select areas throughout the country, but have yet to be undertaken in southeastern Pennsylvania, New Jersey, and Delaware. Given the hypothesis regarding regional differences in the rate of decay, this study set out to assess the decomposition process as it applies to the Delaware River Valley (DRV) region and to provide formulas from which to estimate time since death. The dearth of studies in this area, highlighted the need for region-specific standards, increased the accuracy of time since death estimates, and improved quantitative methods. To this end, a retroactive approach was taken in which cases from the Delaware Office of the Chief Medical Examiner with a known “date last seen” and “date recovered” were compiled. Using these cases, a qualitative analysis was conducted examining the specific decompositional changes which occur in various contexts. Quantitatively, a linear regression analysis was employed to determine if accumulated degree days (ADD) or PMI explained more of the variation in decomposition. To complement this work, a multivariate regression analysis was conducted to identify key covariates and assess their impact on the rate of decay. Lastly, to validate region-specific standards, the DRV models were compared to those presented in Megyesi et al. (2005). For this validation process, a specific progression to decomposition in the DRV was identified and total body score (TBS) systems for both outdoor and indoor cases, and aquatic depositions, were developed. ADD and TBS were determined to be central components in modeling decay. In addition, outdoor cases were demonstrated to decompose fastest. Finally, the DRV model explained more of the variation in decomposition and more accurately estimated ADD than that of Megyesi et al. (2005). In total, a set of time since death estimation formulas applicable to indoor, outdoor, and aquatic contexts were produced, and region-specific standards best-suited to estimating time since death in the Delaware River Valley were developed.

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Chapter One: History of Post-Mortem Interval Studies in Anthropology

When presented with a case, one of the first questions asked by a forensic anthropologist is: How long has this individual been dead? This specific question guides interpretations of the narrative surrounding events, narrows the list of missing persons, confirms or refutes suspects' alibis, and leads to the identification of unidentified remains. In order to make such a determination, the forensic anthropologist must weigh the effects of multiple factors known to alter the rate of decomposition. However, for years, this particular question was outside of the purview of forensic anthropology. Not until the principles of taphonomy were incorporated into physical anthropology, and eventually applied to forensic anthropology, were estimates of the post-mortem interval (PMI) within the bounds of the discipline.

In order to provide a detailed background of the transition from the early days of forensic anthropology to its current constitution, one must consider the paradigm shift which has occurred since Mehmet Yascar Isçan's 1988 discussion of the current state and future of the discipline. In this seminal paper, the purview of forensic anthropology was limited to considerations of sex, age, race and stature of individuals, reducing the field to laboratory-based analyses lacking in quantitative methods, modern comparative samples, and statistical parameters from which conclusions could be based (Isçan 1988). In essence, the goals of the discipline were whittled down to a single task: the determination of the biological profile for the purposes of identification. Nowhere was there a mention of forensic taphonomy, estimates of post-mortem interval, or the reconstruction of events surrounding death, which combine to form a crucial part of modern forensic anthropological examinations (Dirkmaat et al. 2008).

Developments in DNA Analysis

In order to understand the root causes behind the paradigm shift in forensic anthropology and, more importantly, the rationale for conducting decomposition studies within anthropology, two key external factors must be identified, as they set the stage for the diversification of the scope of the field and the formulation of new research questions and goals. Firstly, as the capabilities of DNA for the purposes of identification began to unfold, it became clearer and clearer that eventually the day would come when victim identification via DNA comparisons would be routine, transforming the question from *if* this would happen, to *when* (Dirkmaat et al. 2008). Given this threat to the usefulness and vitality of forensic anthropological analyses, forensic anthropologists were forced to expand the focus of the field beyond traditional determinations of the biological profile to a larger range of problems, or else run the risk of becoming irrelevant (Dirkmaat et al. 2008).

Court Rulings

Secondly, with the Supreme Court ruling on the case of *Daubert vs. Merrell Dow Pharmaceuticals* (1993), *Kumho Tire Co. vs. Carmichael* (1999), and Federal Rules of Evidence rule 702 (2000), scientific conclusions presented by an expert in a court of law were required to be replicable and reliable with consistent results and scientific acceptance, testable via the scientific method, and valid with the determination of statistically estimated error rates when possible (Dirkmaat et al. 2008; Dirkmaat and Cabo 2012). Given the newfound focus on the expert's methods rather than experience, analyses using quantitative methods were preferred over qualitative ones (Dirkmaat et al. 2008). These crucial rulings, combined with the findings of the National Academy of

Sciences' (2009) report on the state of the forensic sciences in the United States, compelled forensic anthropology to improve its methods and the samples upon which its standards were based, in order to demonstrate their validity, reliability, and accuracy, as well as provide statistical interpretations and error rates regarding its analyses.

Paradigm Shift

Faced with the looming impact of the application of DNA analysis to identification and the call for improvements in methodology, forensic anthropology was forced to adapt to new technical and legal challenges or face extinction. In response to them, one of the most crucial developments in the field was the usurpation of the principles of taphonomy. This move transformed forensic anthropology from a lab-based subject to a scientific discipline with a strong field component, providing the anthropologist with a spot in modern-day investigations (Dirkmaat et al. 2008).

Originally developed in paleontology, I.A. Efremov introduced taphonomy (*taphos* meaning grave and *nomos* meaning ordinance or law) as the "study of the transition of animal remains from the biosphere into the lithosphere (Efremov 1940: 83)." The field arose from the need to better understand the processes associated with the preservation of plant and animal materials, especially vertebrates (1940). This specific area of study was initially oriented toward an understanding of the mechanisms that transform the state of body tissues, particularly those aspects most influential in introducing bias into the fossil record (1940). Given the potential for differential preservation, part of that understanding involved not only analyzing how the ecology of sites changed with the introduction of organic material, but also how the site affected the preservation of said material (1940).

From there, taphonomy slowly expanded beyond research regarding the differential preservation of vertebrates to a successful application to hominid sites, first exemplified by Raymond Dart's "osteodontokeratic culture (Dirkmaat et al. 2008; Beary and Lyman 2012)." This new trend was quickly adopted and applied to physical anthropology, and subsequently accepted as a component of archaeological practice as well. The new association meant that the analysis of sites and assemblages could no longer be approached independently by different professionals in different venues, but instead required a partnership between taphonomy and anthropology. By subsuming the principles of taphonomy within the purview of forensic anthropology, the stage was set for the development of renewed goals and an expanded focus in the discipline (Dirkmaat et al. 2008). As the relationship continued to flourish, the collaboration provided forensic anthropology with a pathway to demonstrate its applicability and potential for further informing medico-legal investigations, especially as they relate to estimates of time since death.

As stated by Dirkmaat et al. (2008), forensic anthropology and taphonomy share virtually identical goals, which explains the rapid and dramatic impact that taphonomy has had on the field. It expanded the objectives of the discipline far beyond its original definition, morphing the paradigm previously centered on positive identification into a broader and farther reaching field. Given the changing landscape of forensic science, without the incorporation of forensic taphonomy into anthropological analyses, the field would be headed toward obscurity. More importantly, such a statement reflects why decomposition studies in the present day certainly fall under the purview of forensic anthropology and are necessary to its vitality.

Incorporating Forensic Taphonomy

To help make this point, it will be useful to review the impact of taphonomy on the redevelopment of the goals of forensic anthropology through comparison of the definitions of both approaches. Forensic taphonomy is defined as the “use of taphonomic models, approaches, and analysis in forensic contexts to estimate the time since death, reconstruct the circumstances before and after deposition, and discriminate the products of human behavior from those created by the earth’s…subsystems (Haglund and Sorg 1997: 3).” Likewise, modern forensic anthropology is defined as “the scientific discipline that focuses on the life, death, and the post-life history of a specific individual, as reflected primarily in their skeletal remains and the physical and forensic context in which they are emplaced (Dirkmaat et al. 2008: 47).” Given the shared focus on post-mortem reconstructions and the emphasis on context demonstrated in both definitions, the critical role played by decomposition studies in forensic anthropology becomes self-evident, undoubtedly justifying its inclusion within anthropology. Furthermore, with the determination of statistically backed error rates and research grounded in the scientific method, the incorporation of decomposition studies, and the principles of taphonomy into forensic anthropology, have proven crucial to meeting the demands of greater applicability of the discipline to medico-legal investigations and the improvement of quantitative methods. Without the reformulation of forensic anthropology to include evaluations of the time since death or any of the other applications of forensic taphonomy, the discipline would be well on its way to irrelevancy.

Forensics in Physical Anthropology

Moreover, the renewed focus of the discipline states that forensic anthropology involves the application of physical anthropological principles employed during the reconstruction of identity and events surrounding and subsequent to death, relying heavily upon data collected at a site (Dirkmaat et al. 2008). As stated by Dirkmaat et al. (2008: 47),

> "Physical anthropology is defined and understood as a holistic field, with a conceptual and methodological flexibility that allows the definition [stated] above to fall well within its conceptual framework. Historical considerations, and the training and background of forensic practitioners also justify the inclusion of forensic anthropology as a discipline clearly entrenched in the physical anthropology tradition."

By employing a bioenvironmental and biocultural approach, the principles of taphonomy and thus modern forensic anthropology, are very much in line with the conceptual framework of physical anthropology (Sorg and Haglund 2002). In addition, given the critical need for the search for, recovery, and preservation of physical evidence at the scene, the contextual relationship between evidence and its depositional environment is emphasized, making important use of the principles of archaeology as well (Dirkmaat et al. 2008). Thus, given the importance of time since death studies to the "new" forensic anthropology as evidenced by its reformulated definition, revamped research questions, and renewed focus, PMI research clearly sits squarely within the boundaries of anthropology.

Chapter Two: Forensic Anthropology: Contributions to Anthropological Problem Solving

Given the paradigmatic shift in forensic anthropology over the last quarter century, the discipline's focus has been expanded and its methods have been improved (Dirkmaat and Cabo 2012). As a result, the widened scope of the field has led to new developments and insights which have contributed not only to questions dealing with forensic anthropology, but have also aided in answering broader anthropological questions as well.

Scavenger Analysis

Firstly, forensic anthropology and taphonomic research have many applications to anthropology, specifically as they relate to archaeological and paleoanthropological interpretation of sites and remains. Dating back a half century, archaeologists have been interested in the effects of scavengers, such as canids, on bone debris found at sites (Willey and Snyder 1989). Great examples of such research can be dated back into the late 1970s and 80s, found in the works of researchers such as Binford (1981) and Brain (1981), as they postulated as to the effects of carnivores on prey carcasses and how such taphonomic involvement with corpses could be detected and controlled for. To meet such demands, actualistic taphonomic studies investigating the patterns and sequence of canid consumption, manipulation, disarticulation, and scattering of carcasses began to develop (Hill 1979). The same trend was visible in paleoanthropology, as investigators became aware of the potential alteration of prehistoric skeletal material, forcing reassessments of site behaviors, cannibalism, and so forth (Trinkhaus 1985; Villa et al. 1986). In response, direct forensic anthropological study of carnivore disarticulation and dismemberment patterns on human remains were developed, first pioneered by Haglund et al. (1988) in the 1980s onward. Given the call for such studies, the parallels between forensic anthropology and archaeological and paleoanthropological inquiries, as well as the immense potential for forensic anthropology to contribute to anthropological problem-solving, becomes quite clear.

DNA Analysis

Moreover, one of the most important developments in anthropology deals with the rise of DNA studies and its potential to inform understandings of past peoples, both modern and ancient. By analyzing skeletal samples, DNA studies have the ability to clarify the spatial and temporal associations between and within populations, relatedness of individuals, migrations and origins, and sex identification (O'Rourke et al. 2000; Stone 2000). Thus, these analyses are useful for both forensic and bioarchaeological investigations.

However, one of the largest issues concerning the use of DNA analysis deals with the degradation of samples. Given the fact that forensic taphonomy studies are interested in the decomposition of remains, the determination of the circumstances under which DNA can or cannot be extracted is of critical importance to the field (Beary and Lyman 2012). Thus, a number of studies have been conducted examining how differential preservation, different extraction techniques, and various environmental and taphonomic factors affect cellular integrity and the ability to recover useable DNA samples from bone and tooth remains (Fisher et al. 1993; Rankin et al. 1996; Damann et al. 2002; Kontanis 2003; Latham 2003; Latham et al. 2003; Rennick et al. 2005; Fredericks and Simmons 2008). Although the majority of these taphonomic studies were designed with modern cases in mind, they clearly have applicability to the extraction and analysis of DNA from fossil remains. These particular areas of concern are of importance to understandings of human evolution and developing the narrative surrounding early modern human origins and their relationships vis á vis other hominids. Thus, inferences can be made connecting these forensic studies to prehistoric cases.

Trauma Analysis

Another crucial effect of the widened scope of modern forensic anthropology on broader anthropological issues revolves around developments in trauma analysis. Once again, forensic taphonomy research has provided the impetus for the development of new insights into trauma, given the field's concern with differentiating events before, during, and after death (Dirkmaat and Cabo 2012). Whether remains are relatively "fresh" in nature or hundreds of years old, an assessment of ante-, peri-, or post-mortem damage is of critical importance to reconstructing the events surrounding death and developing inferences regarding lifestyle and cultural norms (Berger and Trinkaus 1995; Neves et al. 1999).

Prior to its development in forensic anthropology, interpretations of human skeletal trauma were based on educated guesses derived from analyses originating out of paleopathology and vertebral faunal analysis (Dirkmaat and Cabo 2012). However, through the pioneering work of Berryman and Symes (Symes and Berryman 1989; Berryman and Symes 1998), the foundation was laid for the development of systematic skeletal trauma research in forensic anthropology. As a result, there has been an increase in the diversification of trauma studies as reflected in the number of publications in the *Journal of Forensic Sciences* and the rise in experimental, actualistic, and doctoral student trauma research (Passalacqua and Fenton 2012). The effects of this diversification have led to much better assessments of the various types of trauma and the development of a more accurate picture of the traumatic event (Dirkmaat 2012). By examining bone biomechanics, analyzing the alteration and modification of remains, considering the taphonomic factors impacting skeletal tissue, and assessing acute versus past trauma, the identification, documentation, and interpretation of trauma has dramatically improved (Symes et al. 2012).

Given the importance of trauma analysis on remains from both past and present peoples, the advancements in trauma research developing out of forensic anthropology can have important impacts not only on modern investigations, but also anthropological inquiries into past ways of life. From there, inferences can be made, providing insights into various aspects of the social, cultural, biological, and ecological circumstances within which past peoples operated.

Distinguishing Archaeological from Forensically Relevant Cases

Another important outcome related to the incorporation of taphonomic analysis in forensic anthropology, and its usefulness to the broader discipline of anthropology, has to deal with the ability to distinguish between cases of archaeological versus forensic value. These determinations are crucial to legal proceedings and adherence to federal mandates such as the Archaeological Resources Protection Act (1979) and the Native American Graves Repatriation Act (1990). Fortunately, given the need to quantify changes in skeletal material in the late post-mortem period, multiple approaches can be taken in this regard.

Clearly, methods typically utilized in the early post-mortem period are not applicable, but analyses have been developed through forensic anthropology and associated scientific disciplines to assess the more advanced stages of skeletonization, and as a direct result, help to identify the forensic relevance of a set of remains. To name a few, these methods include: histological analyses of bone cross-sections (Specht and Berg 1958), measures of citrate content (Schwarcz et al. 2010) and nitrogen and amino acid amounts (Knight and Lauder 1967), ratios of proteins and triglycerides (Castellano et al. 1984), and so forth. More recently, analysis of dental materials in skeletonized remains have been utilized to determine the forensic relevance of remains located in a mass grave found in a suburb of Belgrade (Zelic et al. 2013). Given the plethora of examples which exist, the critical takeaway highlights the applicability of forensic anthropological and taphonomic analyses, originally designed to estimate the post-mortem interval in forensic cases, to establishing the archaeological versus forensic relevance of a set of remains.

Modern Samples

Lastly, given the impetus placed on improving the validity, reliability, and accuracy of forensic methods by various federal rulings (*Daubert vs. Merrell Dow Pharmaceuticals* 1993; *Kumho Tire Co. vs. Carmichael* 1999; Federal Rules of Evidence rule 702 2000), researchers were forced to evaluate the applicability of skeletal collections and the standards derived from them to modern populations (Dirkmaat and Cabo 2012). After a careful analysis of the skeletal samples, it was discovered that many of the major collections were plagued by sampling issues, ranging from a lack of representativeness, to socio-economic biases, questionable age associations, preponderance of old-age samples and outdated data (Meindl et al. 1990; Ousley and Jantz 1998). In addition, as Ousley and Jantz (1998) point out, factors of immigration, emigration, admixture, and so forth have altered the genetic landscape, thus necessitating the development of modern skeletal collections in order to properly interpret remains. As a result, the William D. Bass Donated Skeletal Collection was created, composed of modern skeletal samples, many of which derive from the "Body Farm" project developed out of the University of Tennessee (Wilson et al. 2010). In addition, studies have also amassed records from coroner and Medical Examiner's offices around the country to meet the demand for updated skeletal data (Suchey and Katz 1998; Fojas 2010).

FORDISC

A direct result of such efforts lies with the development of the FORDISC program. By compiling collections from around the globe (including data on Hispanics in the U.S.), utilizing multiple standards, and incorporating measurements from tribal groups and modern day forensic cases, many of which are drawn from the William D. Bass Donated Skeletal Collection, FORDISC (Ousley and Jantz 2005) directly combats the sampling issues known to plague the outdated collections from which many currently used standards are based (Dirkmaat and Cabo 2012). By compiling an extensive collection of modern day measurements, FORDISC allows the comparison of data across generations and even centuries, allowing for the evaluation of secular trends and changes and meeting the demands for the improvement of quantitative methods in the discipline.

Secular Changes

Given the ability to compare past and present populations in regards to various skeletal measurements, the identification of secular changes in growth and maturation has been made possible. As demonstrated by Jantz (2001), over a 125 year period, Black and White cranial metric data have shown vaults that have become markedly higher and narrower, with narrower faces, which is claimed to be due in large part to changes enacted on cranial base growth by improved environmental conditions.

A secular change in height has also been documented, seen mainly as an increase in lower limb length (Weber et al. 1995; Danubio and Sanna 2008; Malina et al. 2010). This argument is made particularly clear by Jantz (1993), who argues for a modification of the female stature formula developed by Trotter and Gleser (1977) to account for secular trends affecting the tibia-femur ratio. Likewise, Ross and Konigsberg (2002) demonstrated that stature estimation from formulas developed for American White males were inappropriate for European populations, as secular changes and allometry of limb proportions resulted in the underestimation of stature in genocide victims in the Balkans.

In addition, as has been demonstrated around the globe, skeletal maturity and the onset of puberty have been shown to arrive months to years earlier than documented decades ago (So and Yen 1990; Hawley et al. 2008). These critical differences are attributed to improved socio-economic, nutritional, and hygienic conditions (So and Yen 1990).

Without updated and modern comparative samples, such as those composing the Bass collection, these changes over time would likely go undetected. Fortunately, the collection of forensic cases from around the country has provided modern data with which to compare to past populations, in order to get at improvements and advances in socio-economic, hygienic, and environmental conditions. These insights into human evolutionary changes and skeletal variation are a fundamental aspect of the overarching themes governing anthropology, and solidify the notion that forensic anthropology is grounded in the principles of physical anthropology (Dirkmaat and Cabo 2012). Given the fact that much of which is known about human skeletal variation and the determination of the biological profile is derived from early examinations of remains from forensic contexts, studies of this nature continue the contributions made by forensic anthropology toward a more complete understanding of human evolution (Kerley 1978).

In summary, the points made above are but a few examples of the many contributions which forensic anthropology makes to the broader questions asked in anthropology as a whole. It is important to understand these contributions as they demonstrate that forensic anthropology has grown into more than an applied, technical field, instead having morphed into a legitimate scientific research discipline with the capability of informing specific questions related to the discipline, as well as contributing to larger anthropological problem solving.

Chapter Three: Theoretical Basis

In order to further frame decomposition studies within the larger discipline of anthropology, a review of the theoretical underpinnings governing forensic anthropology is warranted. Many researchers are wary of applying theory to forensic investigations given the often unique and specific circumstances of individual cases. However, Boyd and Boyd (2011) make a strong argument, summarized below, for the use of multiple and hierarchical levels of theory to address the often disparate goals in forensic anthropology.

High Level Theory

The overarching theoretical umbrella governing biological anthropology is that of evolution grounded in the Darwinian and punctuated equilibrium models, which are also applicable to some extent for the purposes of forensic anthropology. An understanding of the evolutionary forces which govern human variation is a critical component of determining the biological profile and explaining the basis behind the processes involved in skeletal growth, development, degeneration, and secular change. However, given the fact that such processes assist in explaining population variability, while the focus in forensic anthropology is on the individual, an inferential extrapolation is required, leading some to call for the application of middle and lower-range theories to address the unique circumstances faced in a forensic context (Boyd and Boyd 2011).

Middle-Range Theory

Taphonomic Theory

Middle-range theories transform static observations into inferential statements about the dynamic processes that produced the forensic record, linking materials, context, and recovery into explanations of human behavior. These connections are often made through actualistic studies, under which decomposition studies fall. Taphonomic theory is a critical part of time since death evaluations, used to examine the roles of human and non-human forces, as well as the natural and cultural processes which affect a scene, to aid in the reconstruction of forensic events. Thus, observations regarding decomposition, animal and insect activity, plant disturbance and so forth, are used to enhance inferences about the effects of these processes in the past. Context also plays a crucial role, further incorporating the principles of archaeology into interpretations of past events (Boyd and Boyd 2011).

Non-Linear Systems Theory

The approach taken by non-linear systems theorists are also applicable, especially in regards to decomposition studies. These theorists reject the traditional Newtonian model of isolating variables while controlling for others. Instead, they emphasize multivariate analyses in actualistic, real-life situations, recognizing the complex properties and context of systems, noting the often intertwined and tight-knit relationship of various factors and variables involved in forensic scenes. Given the high degree of interrelation amongst these critical variables, they would argue against the possibility of parceling out individual factors, as the result would not be representative of the actual processes in play. It also uses computer simulations to provide predictive models which have the potential to incorporate human decompositional data to improve the accuracy of time since death estimations (Boyd and Boyd 2011).

Agency and Behavioral Theory

Researchers also call for the use of agency and behavioral theories when examining forensic settings. In essence, these theories recognize that humans have agency, but at the same time are restricted by the social structure and context in which they are operating (Boyd and Boyd 2011). Lovis (1992) and Mizoguchi (1993) support such conclusions, pointing out the roles played by social structure, memory, and routinized, repeated actions in constraining practices as they relate to mortuary anthropology. Boyd and Boyd (2011) take it a step further, applying the principles to interpretations of forensic scenes as well. As they point out, investigators must not only recognize the role of agents in the original event, but the role that they themselves play in the scene, as their presence and interpretation alters the post-event context as well. In this way, both time and space are meaningful dimensions for all agents involved.

Low-Level Theory

Lastly, low-level theories are also useful for guiding the questions asked in regards to the often unique circumstances posed by forensic cases, as well as directing which analyses should be used. In terms of the relationship between method and theory, modern forensic anthropological thought suggests that no clear-cut distinction exists between the two. As much as theoretical questions inform analyses, the methods available can also affect the interpretation of data. Thus, if a method consists of tools applied to achieve certain goals, then a theory can function as method as well. In this way, there is an underlying theoretical basis in everything a forensic anthropologist does (Boyd and Boyd 2011).

Given the often specific and unique circumstances which forensic settings possess, Boyd and Boyd (2011) argue for the use of multiple theoretical “levels” in order to best understand, analyze, and process a scene. This particular dissertation research study will take heed of these suggestions, incorporating all of the aforementioned theoretical levels to various extents.

Chapter Four: Statement of the Problem

In order to demonstrate the need for a study of this type, the problem statements to be addressed by this research will be detailed below. They are intended to serve as a rationale for this study and demonstrate why it warrants extensive research. Given the critical importance of quantitative applied, actualistic decomposition studies, seven main problem areas have been identified, as follows.

Primary Problem Statement: Need for Region-Specific Studies and Standards

Post-mortem interval estimates play a critical role in criminal justice and medico-legal investigations. These estimates are based on decomposition standards developed through research in select areas. These studies developed out of a need to understand the process of decomposition and qualify the effects of various environmental, scene-specific, and depositional variables on the rate of decay so as to provide estimates regarding PMI. However, these standards are known to vary in effectiveness and applicability based on the particular environmental region in which they are being employed. Unfortunately, this variability has led to a significant gap in scientific knowledge regarding the rate of decomposition in areas outside those regions previously studied.

Without knowledge of the environment in which decomposition is taking place, not much can be said regarding the time since death. In order to understand its impact on the rate of decomposition and the primary problem statement to be addressed by this study, one must appreciate the wide-reaching effects of temperature. In fact, the most important factor affecting the rate of decomposition has been determined to be temperature, as it guides the degree to which other variables affect decay (Gill-King

1997; Nawrocki 2011). Its critical influence has been identified to impact a number of variables important to the decomposition process including bacterial growth, humidity, aridity, scavenging activity, adipocere development, and so forth. Most importantly, although insect activity has been identified as a primary player in decomposition (Simmons et al. 2010a; 2010b), temperature provides the optimal range of conditions within which flies, maggots, larvae, and pupae can most effectively and efficiently consume tissues. Thus, common sense dictates that the warmer the temperature, the quicker soft tissue will decompose, with the inverse applying to cold climates. These assumptions have indeed been validated by studies examining decay rates in both hot (Galloway et al. 1989; Parks 2011) and cold environments (Komar 1998; Bunch 2009; Bygarski and LeBlanc 2013).

Another important point to make here revolves around the relationship between desiccation and putrefaction. Desiccation, whether through aridity in hot climates or freeze-drying in the cold, can preserve remains, oftentimes leading to mummification. Given the drying out of tissues which accompanies desiccation, insect activity can be greatly retarded, requiring moisture in order to oviposit eggs (Haskell et al. 1997). Putrefaction on the other hand operates in the presence of moisture and moderate temperatures, as it is guided by bacterial action (Micozzi 1997). Decomposition taking place in an environment with temperatures between 60-95 degrees F will be rapid, as bacterial growth and cell division occur best under these conditions (1997). However, once temperatures begin dropping below that optimal range and approach the freezing point, bacterial reproduction, coupled with insect activity, becomes greatly retarded, eventually stopping altogether. At higher temperatures, a competition between desiccation and bacterial growth occurs, with the outcome depending on the relative humidity (1997). Thus, the intricacies of decay demonstrate the profound impact which environmental variables, especially those inextricably linked to temperature, have on decomposition.

Moreover, and perhaps more importantly, differential decomposition has been observed when assessing factors beyond temperature in a variety of climates and environmental regions. A great example revolves around the effect played by scavenging activity on the breakdown of a corpse. When comparing the pattern and timing of vulture scavenging in Central Texas and Southern Illinois for example, differences are observed in the feeding patterns, rapaciousness, time to skeletonization, group size, and time required to find remains (Reeves 2009; Dabbs and Martin 2013).

In another example, insect successional patterns in subtropical southeastern Texas were studied (Bucheli et al. 2009). Although the usual, expected, forensically significant insects were seen to be present, less commonly encountered insects, such as live case-making clothes moths were also observed (2009). In total, the insect fauna represented a unique assemblage particular to that environment and time of year. In this way, insect succession is precisely correlated with each geographical region (Anderson 2010). As emphasized by Bygarski and LeBlanc (2013: 413), “biogeoclimatic range has a significant effect on insect presence and rate of decomposition, making it an important factor to consider when calculating a postmortem interval.” Given the crucial role played by insects in regards to the breakdown and consumption of tissues, these studies are great examples of how differences in decomposition can result due to differing taphonomic factors between various environmental areas.

As explained by Dabbs and Martin (2013), these discrepancies highlight a critical point: the effects of taphonomic agents, such as scavengers and insects, vary with climate and region and may thus differentially affect decomposition rates and patterns. The differences in the timing and pattern of scavenging activity by similar species in different environments, as well as the unique assemblage of insect activity observed, not only brings to light extreme variations in decomposition rates and patterns, but also reiterates the need for site-specific taphonomic data collection (2013). As Haglund (1997: 379) points out, "any assessment of postmortem interval is extremely area dependent and does not depend on a single criterion." Given these dependencies, a "one size fits all" decomposition model is unrealistic (Parks 2011: 19), thus necessitating region-specific studies.

However, despite the clear effect of environment on altering the decomposition process, decomposition studies evaluating the time required to progress to specific decompositional states have only been conducted in certain areas of North America, heavily focused on the southeastern and southwestern United States. Famous among them are studies conducted by Allison Galloway et al. (1989) in the Arizona desert, Debra Komar (1998) in the cold climate of Edmonton, Alberta, and Rodriguez and Bass (1983; 1985), as well as Mann et al. (1990) and Vass (2011) in the humid subtropical climate of East Tennessee. Since these studies were published, a string of additional decomposition studies were developed in various regions of the country including Central and southeastern Texas (Bucheli et al. 2009; Parks 2011), California (Dupuis 2005), the Carolinas (Alberti et al. 2006), New England (Colleran 2010), and Colorado (Allaire 2005) to name a few.

Despite studies being scattered throughout the country, one glaring gap in decomposition research remains, the Mid-Atlantic States, particularly the Delaware River Valley area, comprising southeastern Pennsylvania, New Jersey, and Delaware. This dearth of research has led to a significant gap in knowledge regarding the process of decomposition as it applies to this specific environment. As noted through various studies on the rate of decay, environmental differences can have a tremendous impact on PMI estimates across regions (Jaggers and Rogers 2009; Parks 2011; Dabbs and Martin 2013). As a result, it is currently unknown whether standards from other regions of the country apply to this area or if time since death estimation methods specific to the region are needed to ensure the accuracy, validity, and reliability of time since death estimates.

As an example, based on the location of previous decomposition studies, the evaluation of time since death in this area is theoretically supposed to be drawn from standards developed out of Tennessee. However, a comparison of both regions demonstrates clear differences in a number of environmental categories including temperature, humidity, precipitation, and snowfall (NOAA et al. 2013). What's more, these factors have been demonstrated to greatly alter the decomposition process (Mann et al. 1990). Thus, given the clear differences between both regions, time since death estimates derived from studies based on the particular climatic conditions in Knoxville, may very well be inapplicable to the Delaware River Valley area. In fact, even researchers at Tennessee (1990: 110), recognizing that climatic conditions appear to have the greatest effect on decay, have made it clear that it is "imperative that further research be conducted…in many other states where temperatures and other environmental and ecological factors differ from those in east Tennessee." This point is made even clearer by Jaggers and Rogers (2009: 1221) who state, "The complex relationship that exists between decomposition and temperature also illustrates the importance of being cautious when applying experimental results obtained in one region to different geographical areas."

Along the same vein, researchers have also urged that such studies be undertaken so as to create a country wide post-mortem interval database and formula, accounting for different environmental pressures affecting remains as they breakdown, further highlighting the need for additional input by the forensic community so that these models can be adjusted and corrected for varying environments and circumstances not yet evaluated (Vass 2011). Therefore, the development of accurate time since death determination methods are not just crucial for the Delaware River Valley Region, but can also contribute immensely towards efforts aimed at standardizing the estimation of time since death throughout the World.

Thus, given the call for decomposition studies in a variety of climates, if the accuracy, validity, and reliability of time since death estimates is desired, an informed understanding of the decomposition process as it applies to the Delaware River Valley is required. As I.A. Efremov (1940: 82) stated upon beginning the field of taphonomy, apart from the study of fossilized objects in and of itself, the only other way to the knowledge of the animal world of past eras is through "a comparative study of the localities where the remains have been found." Therefore, one of the primary problematic areas to be attacked by this study is the crucial lack of decomposition research in this particular environmental region. Given the hypothesized regional differences in decomposition and the dearth of applied studies in the Delaware River

Valley area, this study sets out to understand the process of decomposition as it applies to this specific region and develop a region-specific formula by which to estimate time since death.

Secondary Problem Statement: Call for Improvements in Quantitative Methods

In addition to the glaring issue demonstrated by the lack of decomposition studies in the area, another important gap in scientific research can be addressed by this study. Given the potential for inaccurate time since death estimates in regions where no applied studies have been conducted, coupled with concerns regarding the reliability and validity of PMI estimation methods in those areas, assertions of time since death by forensic experts in a court of law are now open to question.

Beginning in 1993 with the Supreme Court ruling in the case of *Daubert vs. Merrell Dow Pharmaceuticals*, and continuing with the *Kumho Tire Co. vs. Carmichael* (1999) case, as well as the Federal Rules of Evidence rule 702 (2000), scientific conclusions presented by an expert in a court of law are required to be replicable, reliable, and valid with consistent results, scientific acceptance, and the determination of statistically-backed error rates (Grivas and Komar 2008; Page et al. 2011a; 2011b; Dirkmaat and Cabo 2012). In fact, in a study evaluating the most effective PMI estimation techniques, error ranges are called for to prevent the overestimation of time since death (VanLaerhoven 2008). Given the newfound focus on the expert's methods rather than experience, analyses using quantitative methods are now preferred over qualitative ones (Dirkmaat et al. 2008). These crucial rulings, combined with the findings of the National Academy of Sciences' (2009) report on the state of the forensic sciences, compelled the field to improve its methods and the samples upon which its standards are based, in order to demonstrate their validity, reliability, and accuracy, as well as provide statistical interpretations and error rates regarding its analyses.

However, despite the rulings laid out in these mandates, significant progress still needs to be made. In a retroactive study of 548 judicial opinions from cases where admission of forensic identification evidence was challenged, it was discovered that 15% involved exclusion and limitation of identification evidence, with 65.7% failing to meet the reliability threshold (Page et al. 2011a). The cited reasons for such exclusions of evidence highlight unfounded statistics, error rates, and certainties, failure to document the analytical process or follow standardized procedures, and the existence of observer bias (Page et al. 2011b). As Page et al. (2011a: 1184) make clear in the first part of their two-part series examining forensic identification evidence, "in such cases, the reliability of forensic identification science evidence, encompassing the concerns regarding the discipline's underlying theory, the expert's testimony, and their methodology, accounts for the majority of judges' concerns regarding its admission." More frightening is the suggestion that up to 60% of trials where defendants were initially found guilty but later freed via DNA testing, relied on invalid forensic science testimony (Garrett and Neufeld 2009). What's more is the claim that some of the forensic sciences have been around for so long that judges admit evidence even if they fail to meet minimum standards (Moriarty and Saks 2005). Lastly, as best summarized by Page et al. (2011b: 917), "It should be noted that none of the issues discussed in this paper can be successfully addressed by the legal community. It is up to the practitioners and researchers in our discipline to ensure that forensic science is able to provide information of the standard that the judiciary desires and that defendants are entitled." Therefore, not only is it crucial that quantitative methods be improved, objective standards be developed, and statistical backing be provided to ensure the admissibility of forensic identification evidence in court, but to ensure the punishment of the guilty and the freedom of the innocent.

As a result, a push has been made in the forensic sciences to improve its quantitative methods and standards, so as to meet the call for statistically-supported conclusions. Given the recommendations laid out by the various court mandates, decomposition standards lacking a statistical foundation are susceptible to scrutiny by both the presiding judge and cross-examining attorney. Thus, it would behoove the criminal justice community to support the development of studies which can meet those requirements so as to make crucial pieces of forensic evidence and testimony admissible in a court of law. Unfortunately, a large number of decomposition studies lack statistical evaluations, instead solely reporting the general timeframe within which patterns of decompositional change occur. This proposed study however, plans to go beyond such qualitative patterning by using a quantitative analysis. Through multivariate regression analyses and the development of a regression equation by which to estimate time since death, this research will be able to provide more than general stages of decomposition, instead devising a formula by which to predict the time since death within a confidence interval, as well as provide statistically-backed error rates for each prediction. In this way, testimony derived from estimations utilizing the time since death formula will meet the call for improvements in quantitative methods, abide by all mandates, and be admissible in a court of law.

Therefore, by filling these significant gaps in scientific research and knowledge, criminal investigators and forensic practitioners will be able to ensure the accuracy, reliability, and validity of time since death estimation methods, a tremendous advantage when conducting criminal and medico-legal investigations and supporting assertions made in a court.

Tertiary Problem Statement: Development of an Effective Method by which to Quickly Estimate PMI to Assist Scientific Criminal Investigations

Given the issues presented in the previous two problem statements, if decomposition standards which are not applicable to the region are being used, then estimations of time since death can be grossly under or overestimated, leading to the development of false leads and precluding possible identifications. These errors in time since death attribution can have long-reaching effects, as they play a critical role in scientific criminal investigations. Besides the obvious use of time since death estimations for determining the length of time an individual has been expired for, these estimates are also important aspects of efforts dedicated toward narrowing the list of missing persons and identifying unknown individuals, helping to recreate the narrative surrounding an individual's death, establishing a temporal connection to a possible perpetrator, confirming or refuting a suspect's alibi and/or eyewitness testimony, and closing a case.

Often forgotten is the fact that investigators and police personnel handling a case are constantly working against the clock, tasked with assessing the scene, developing a narrative of events, and quickly identifying leads. Given the short timeframe in which investigators have to track down potential suspects, wasted efforts can greatly reduce the probability of closing a case and securing justice. If a valid and reliable time since death formula is available whereby a rather quick estimation of time since death can be produced, investigators will have launch point from which to work from within a relatively short time frame after the recovery of a body, and thus, be able to begin their investigation sooner, potentially facilitating a quicker identification of missing persons and perpetrators.

Therefore, by developing an effective method by which to quickly and accurately estimate time since death, this research will facilitate the identification of unknown remains, track down leads, evaluate eyewitness testimony, corroborate or refute suspect alibis, and ultimately, close cases.

Quaternary Problem Statement: Limited Decomposition Studies Utilizing "Real-Life," Actualistic Forensic Case Data

Due to a number of complicated issues revolving around confidentiality, access to data, varying collection methods, and so forth, limited data regarding time since death determination in real-life cases are currently available. In order to procure such data, relationships and agreements must be established between Medical Examiners and researchers, often becoming ensnared in legal hurdles. As a result, many decomposition studies are conducted experimentally, in controlled conditions, not taking into account the variability and range of possible factors which can affect remains in real-life situations (Mann et al. 1990).

In particular, these decomposition studies are conducted on "body farms," where unrealistic conditions exist, such as protective fencing to prevent predator access (Jeong et al. 2014), installation of cameras whose subsequent clicking scares off carnivores (Meyers et al. 2014), and prior freezing of corpses (Roberts and Dabbs 2014). This last point is of particular concern given the generally accepted method of freezing pig and human carcasses before experimental studies on body farms. As demonstrated by Micozzi (1986; 1997), freeze-thawed rats show markedly higher rates of external decay and disarticulation than in freshly-killed untreated controls, directly resulting from increased mechanical injury in the tissues of previously frozen animals. Although pig cadavers are claimed to be the best human models available (Schoenly et al. 2007), given their similarities in integument, size of the thoracic cavity, internal organs, relative hairlessness, and gut fauna, and thus preferentially used in experimental decomposition studies, it is not a stretch by any means to believe the same processes apply to previously frozen pigs as well. In fact, Roberts and Dabbs (2014) demonstrate significant differences in the rate of soft tissue decomposition between previously frozen and never frozen domestic pigs. From there, the logical leap regarding the errors resulting from the use of frozen human bodies in experimental studies can be made as well.

This is not to mention the potential development of early decompositional changes from the failure to quickly or adequately refrigerate remains, leading to a misinterpretation of the time since death (Zhou and Byard 2011). Just as importantly, are the potential effects of frozen corpses on the arthropod community, as it is widely known that blowflies require moist tissue in order to oviposit their eggs (Haskell et al. 1997). Given the tremendous role played by the insect community in the decomposition process, potentially delaying the onset of insect activity can have a tremendous impact on the accuracy, validity, and reliability of time since death estimates derived from experimental studies using frozen carcasses. As both Schoenly et al. (1999) and Micozzi (1986; 1997) suggest, all experimental studies should employ the use of fresh carcasses over previously-frozen bodies, or risk invalidating study results.

Along the same vein, given the need for experimental investigators to assess decomposition, count insect species and maggot mass size, measure weight loss, and so forth, physical disturbance of the site results. As shown by Adlam and Simmons (2007), disturbance can retard the rate of decomposition by altering the activity of insects. This conclusion is supported by Cross and Simmons (2010), who state that the effect of investigator disturbance was significant when decomposition was measured in the form of weight loss. In turn, given the interruption of the natural forces at play during decomposition, these experimental taphonomic studies may not be accurate reflections of decay in real-life scenarios; therefore, once again substantiating the need for actualistic studies.

Additionally, as mentioned above, although pig carcasses are believed to be the best analogues for human decomposition, research by Stokes et al. (2013) cautions against the use of animal models for specific measurements and studies. In particular, the research found many differences between porcine, bovine, and ovine skeletal muscle tissues compared to humans in decomposition soil studies (2013). Although they argue that enough similarities exist showing cause to continue considering animal models in taphonomic studies, ovine, not porcine, tissue was the most similar to humans in many of the measurements taken (2013). Given the differences described, as well as the results in support of ovine models, potential concerns can be raised surrounding the use of animal carcasses as analogues for human decomposition in experimental studies.

Furthermore, as detailed by Willey and Snyder (1989), most experimental studies control the access of scavengers to the corpse. Commonly used techniques involve protective fencing and the use of cameras to monitor daily activity. In turn, given the ability of scavenging activity to hasten physical decomposition, not only does the pattern of scavenging change, but so does insect succession, the context of the site, and most importantly, the rate of decomposition (1989). Given the alteration of the normal processes involved in real-life forensic scenes, these experimental studies champion their results as unbiased and controlled, when in reality, they lack the realistic conditions to which normal cases are exposed. In total, these experimental studies, although attempting to control for and isolate variables, introduce new and confounding factors not traditionally seen in actual, real-life forensic cases, raising concerns regarding the validity of experimental study results.

When these glaring issues are coupled with the fact that many researchers studying decomposition do not have access to outdoor research facilities to longitudinally quantify the process, most especially in the Delaware River Valley area, it becomes blatantly obvious that actualistic studies must be conducted utilizing real life forensic cases, so as to compile and quantify cross-sectional data from Medical Examiner sources, to allow reliable inferences of the post-mortem interval in different regions of the country (Marks et al. 2009). Without these applied, actualistic studies, there would be no means of evaluating the conclusions developed from outdoor, experimental research facilities under real-life conditions, serving as a necessary method of checks and balances in the forensic science community.

Fortunately, given the fact that this study proposes to collect data from past records and present cases, the need for applied, actualistic, real-life studies will clearly be addressed. The data set will yield information pertaining to variables encountered in the field, not solely single sets of variables pre-determined to be “interesting” by experimental research designers. The variables are presented as is, with no confounding factors or unrealistic conditions. It is hoped that by conducting a study of this type, time since death determination in the Delaware River Valley will more closely approximate the actual rate of decomposition and serve as an effective predictor of time since death.

Quinary Problem Statement: Limited Decomposition Studies on "Non-Standard" Conditions

Furthermore, limited data are available for the application of time since death determination methods to "non-standard conditions," i.e. situations which are not traditionally replicated in controlled, experimental studies (Karhunen et al. 2008: e17). These conditions include investigations of aquatic decomposition, scavenging activity, indoor decay rates, and the like (Henssge and Madea 2007; Heaton et al. 2010; Ross and Cunningham 2011).

Given the estimated differences in the rate of decay between various depositional contexts, this particular gap in research is of particular concern (Maples and Browning 1994). As a matter of fact, in regards to aquatic decomposition, each year, more than 140,000 individuals die in aquatic contexts, further exacerbating the issues stemming from the lack of post-mortem submersion interval studies (Yorulmaz et al. 2003). One glaring stat highlighting this discrepancy demonstrates an 80-20% difference between research conducted in terrestrial versus aquatic environments (Merritt and Wallace 2010). Part of the reason for this dichotomy is the belief that insects have evolved to feed on carrion on land, as opposed to water, and therefore a good deal of research has focused on the use of insects in determining time since death in terrestrial contexts (Wallace et al. 2008). Unfortunately, this has led investigators to often overlook the utility of aquatic insects for estimating the post-mortem submersion interval and has resulted in a dearth of aquatic decomposition studies in general.

Despite its importance, few studies have taken a quantitative approach to modeling the post-mortem submersion interval, focusing instead on qualitative descriptions and factors such as the effects of water depth and sediment on decomposition, terrestrial entomology, aquatic insect and scavenger succession, adipocere formation, and individual case studies (Payne and King 1972; Boyle et al. 1997; Clark et al. 1997; Sorg et al. 1997; Kahana et al. 1999; Hobischak and Anderson 1999; Ebbesmeyer et al. 2002; Hobischak and Anderson 2002; Anderson and Hobischak 2004; Petrik et al. 2004; O'Brien and Kuehner 2007). Although the breadth of knowledge exists, most post-mortem submersion interval studies have failed to incorporate the joint effects of these variables on decay and meet the call for improved quantitative methods.

Likewise, it is interesting to note that scavenging has yet to be evaluated in conjunction with the standardization of time and temperature, measured as accumulated degree days (ADD). As noted by Simmons et al. (2010a), all experimental studies reported in the literature have controlled for this factor. In regards to all of the cross-sectional studies conducted, which may have included scavenging activity in their research design and data analysis, none have reported temperature in the form of ADD or presented the degree of decomposition as a quantitative score (2010a). Therefore, quantitative studies incorporating scavenging activity into the research design, as well as an evaluation of its impact on the rate of decomposition as measured using ADD, are solely needed.

Additionally, despite the frequent occurrence of death within the confines of a home, indoor studies are severely lacking in North America. When this consideration is coupled with the fact that a majority of individuals in the United States live in metropolitan areas, indoor studies, in both urban and suburban areas, appear crucial to a complete understanding of decomposition. However, despite the clear and obvious need for indoor studies, only a few *outdoor* research projects have ever been conducted in urban and suburban areas in North America (Baumgartner 1988; Goff 1991; LeBlanc and Strongman 2002; Simpson and Strongman 2002); plagued by issues surrounding foul odors, community approval, ethics, and the like. In fact, no carrion research had ever been conducted *inside* houses before Anderson in 2011, primarily relying on anecdotal case histories for guidance regarding indoor decomposition (Goff 1991; Benecke 1998). As a result, little is known regarding decomposition rates and insect ecology both within and outside a home in these areas (Anderson 2011). Therefore, given the potential differences in regards to not only insect activity, but also temperature, scavenger access, shade, rainfall, exposure to humidity and aridity, and so forth, between outdoor and indoor contexts, quantitative studies must be developed to account for all of these variables and foster a more informed understanding of indoor decomposition. Fortunately, given the accessibility of data from the Delaware Office of the Chief Medical Examiner, all of the aforementioned issues can be tackled and addressed.

Firstly, due to the variability in the types of cases handled by the Medical Examiner's office, "non-standard conditions," including a range of cases from the fresh to completely skeletonized stages, in a variety of depositional contexts, will undoubtedly be dealt with. This will surely assist investigations dealing with atypical conditions upon which research is usually lacking. Secondly, the use of retroactive studies can be particularly effective in the collection of data pertaining to indoor cases, especially given the issues mentioned above regarding odor, community sentiment, ethics, and so forth. Moreover, multivariate approaches to these types of “non-standard” cases can be extremely useful as well, not only modeling temperature or insect activity, but attempting to understand how additional factors, such as shade, lack of rainfall, scavenger access, and so forth, work in unison to impact the rate of decomposition. Lastly, given the location of the state, the Delaware Office of the Chief Medical Examiner is an ideal setting to conduct a study of this type. Beyond the stated fact that studies need to be conducted in this region in order to assess the differential effects of environment and climate on decomposition and time since death estimation, Delaware’s proximity to the ocean allows the analysis of cases deposited in marine environments. All states are presented with cases involving surface, buried, and indoor contexts, but only a few deal directly with cases involving submerged remains in marine scenarios. Being able to directly evaluate the effect of aquatic environments on decomposition, in contrast to terrestrial and indoor decomposition, will likely produce important insights into the most important factors affecting decay, as well as the impact played by depositional environment. In total, this study may provide insights into previously under-studied research components, potentially widening the scope of future projects by tapping into areas previously neglected in the literature.

Senary Problem Statement: Lack of Studies Incorporating Skeletal Decomposition

As a general rule, decomposition studies have tended to avoid the inclusion of the skeletal phase of decomposition in analysis. In fact, the majority of studies conducted on

PMI focus on soft tissue deterioration (Henssge and Madea 2007; Jaggers and Rogers 2009; Ross and Cunningham 2011), with very little information existing regarding the determination of PMI once remains have skeletonized (Gill-King 1997). In those studies that do take skeletal deterioration into account, they tend to focus primarily on bone biochemistry and microstructure (Specht and Berg 1958; Castellano et al. 1984; Schwarcz et al. 2010). However, given the technical expertise required, as well as the high costs and destructive methods utilized, these approaches have several drawbacks.

Additionally, historically speaking, decomposition has been described as passing through fresh, bloat, decay and dry phases only (Rodriguez and Bass 1983). These dry phases tend to include mummification and lump all aspects of skeletonization into one category. Despite the clear and obvious gap in skeletal research as it relates to time since death estimation, for several different reasons, skeletonization has been viewed as the end point of decomposition and too difficult of a variable to model.

The arguments against including skeletal breakdown as a part of analysis are multi-fold. To begin, the most practical reason behind this discrepancy is the simple fact that remains are much more likely to be discovered in the earlier phases of decomposition. Thus, studies have focused on the early post-mortem period, limiting the amount of information regarding the reduction of a body to its skeletal elements.

Additionally, skeletonization has been portrayed as not being particularly useful in regards to prediction. One particular example is seen in the work of Vass et al. (1992), which seeks to detect the post-mortem interval using chemical analysis of soil solutions. Studies such as this view the onset of skeletonization as the point in which volatile fatty acids stop being secreted; therefore losing the ability to measure their ratios in soil solution. In such studies, the differences between early phase skeletonization, in which grease is retained, and the dry, porous, and fragile end stage of skeletonization, are ignored and lumped together as ineffective predictors of time since death. Likewise, the University of Tennessee's post-mortem interval formula stops at the point of skeletonization, utilizing 1285 as the constant representing the empirically determined ADD value at which volatile fatty acid secretion from soft tissue ceases and the skeletonization phase commences (Vass 2011).

Moreover, Megyesi et al. (2005), the authors of perhaps the defining study of the new quantitative method paradigm shift in forensic anthropology, only include cases with a known PMI period of less than one year, seeing as to how soft tissues are rarely present beyond one year post-mortem. Fortunately however, unlike many other studies including skeletal breakdown, they make larger strides in regards to describing multiples stages in the skeletonization phase provided in their total body score scoring system. Although it is not completely satisfactory, at least in regards to the pattern of decomposition seen specifically in the Delaware River Valley, it is a step in the right direction.

Given the turn away from the analysis of skeletal elements as a predictor of time since death in forensic anthropology, multiple studies, beyond traditional evaluations of rigor, livor, and algor mortis, have focused on prediction in the early post-mortem period. Entomological standards have sought to model the successional patterns of insects, as well as their relative number and ratios (Rodriguez and Bass 1983; Keh 1985; Rulshrestha and Chandra 1987; Haskell et al. 1997). Multiple mathematical approaches to pathology have been employed, seeking to model the relationship between temperature and time through various measures including unsteady heat transfer (Smart 2010) and internal body temperature (Al-Alousi et al. 2001a; Al-Alousi et al. 2001b), subsequently developing nanograms to chart their relationships (Henssge and Madea 2004; Henssge and Madea 2007). Biochemical research has focused on such aspects as the ratio of volatile fatty acids in soil solutions under decomposing bodies (Vass et al. 1992; Vass et al. 2002), as well as changes in blood and cerebrospinal fluid and the potassium content of the vitreous humor (Coe 1993). Taken as a whole, all of these methods have had significant success in this regard.

However, despite the utility of these types of studies to estimating time since death within days or hours, these methods are applicable only when the post-mortem period is relatively short. As cases progress through the decompositional stages and unidentified persons become more and more difficult to match via conventional means of identification, these studies lose their effectiveness and applicability. In turn, time since death periods of increased length fall into the laps of forensic anthropologists, who, as of yet, have been unable to quantify skeletal changes with more precise estimates of time since death and, as described above, have left this aspect of research relatively understudied. This then raises the question: have forensic anthropologists shied away from skeletonization in decomposition studies because of the purported difficulty in modeling it? Although the question remains unanswered, it is readily apparent that associated disciplines have identified the potential insights which analysis of skeletonization can provide.

When assessing the number and types of studies conducted in surrounding fields, it becomes clear that skeletonization has been identified as a useful indicator and component of time since death estimation methods. Bone studies ranging from analysis of histological components (Specht and Berg 1958), citrate content (Schwarcz et al. 2010), measures of nitrogen and amino acid amounts (Knight and Lauder 1967), protein and triglyceride ratios (Castellano et al. 1984), image analysis of luminol application (Introna et al. 1999), quantity of carbon 14 (Hedges et al. 2007) and strontium 90 (MacLaughlin-Black et al. 1992) in bone material, and many more, have all been developed to tap into this neglected research area. Even botanical analysis has been utilized on occasion to estimate the minimum post-mortem interval in cases involving an advanced state of skeletonization (Cardoso et al. 2010).

Nonetheless, despite their applicability to a much neglected aspect of decomposition studies, several drawbacks exist. To begin, the processes involved with these methods require sophisticated and expensive equipment, likely not to be practical for medico-legal agencies or police forces with limited budgets (Jaggers and Rogers 2009). Given the current financial climate, coupled with the lack of investment in the dead, these state of the art methods are most likely out of the reach of many investigators. Secondly, given the use of histological methods and micro-structure analysis, the sectioning process is inherently destructive (2009). If bone remains display forensically important lesions or marks, it may be inadvisable to send remains for these types of procedures. Also, if a limited number of bone remains were recovered, or previous DNA extraction attempts proved insufficient, additional destructive procedures may be looked unfavorably upon by Medical Examiners or forensic personnel. Lastly, despite the direct application of these studies to bone remains, they are relatively imprecise. Given the need to develop more specific time ranges to increase the effectiveness of time since death estimates for tracking down missing persons, identifying suspects, and closing cases, methods better-suited to the forensic community are needed.

Still, despite the nondestructive, repeatable, and lost-cost nature of macro-structural analysis, very few studies have incorporated macroscopic criteria into methods for estimating time since death in skeletal remains (2009). Therefore, given the absence of accurate, non-destructive, macro-structural methods for time since death determination, it appears only logical to attempt to develop a method which incorporates the skeletal period into forensic anthropological analyses of time since death.

Indeed, common sense dictates that accurate time since death estimation methods are absolutely crucial in such advanced stages, especially when taking into account the fact that identifications tend to be much more difficult when remains lack soft tissues. In fact, the lack of decomposition studies incorporating skeletonized remains only exacerbates a glaring issue involved with estimating time since death: there already exists an inverse relationship between the accuracy of estimates and the longer one has been deceased (Schoenly et al. 1999). Thus, if unreliable data exists regarding the later stages of decomposition, this inverse relationship will only increase, severely damaging hopes of identifying remains and suspects, and closing a case. As summarized by Swift (2006), when decomposition has entered the late post-mortem interval period, resulting in only skeletal elements, dating of the time since death becomes more difficult.

Therefore, this particular study plans to not only include skeletonized cases into its quantitative analysis, but it also seeks to move away from the trend of describing the skeletal phase as a single step, instead identifying and more narrowly defining the multiple steps between the early skeletonization period and the dry end stage of skeletonization. Additionally, given the retroactive approach toward data accumulation to be employed by this study, the sample size of skeletonized cases from which conclusions will be drawn, will be much more robust than that seen in previous experimental studies, which typically involve only one or two corpses. By increasing the amount of skeletonized cases in the dataset, a more well-informed understanding of the time required to progress to that stage of decay will develop; thus assisting in decreasing the inverse relationship between the accuracy of PMI estimates and time, and filling the gap in research and knowledge regarding the skeletal period.

Septenary Problem Statement: Traditional versus Quantitative Approaches to Modelling Decomposition

Quantitative versus Qualitative Analysis in Decomposition Studies

From the very onset of decompositional and taphonomic studies in forensic anthropology, researchers have sought to identify patterns in decomposition and associate them with time intervals to aid in estimating time since death. Traditional approaches used qualitative descriptions of the stages of decomposition, which were then each associated with broad time intervals either through simple observation, experience, or experimental study. However, as stated by Stephen Nawrocki (2011: 2), this particular approach is both ineffective and imprecise, while lacking the quantitative backing characteristic of more modern scientific approaches,

> "Traditionally, descriptions of the decomposition status of human remains have been rather qualitative, with the corpse being placed into one of a few broadly-defined stages or categories defined on the basis of the presence or absence of a few key indicators. Stages such as "pre-bloat" or "advanced skeletonization" are necessarily imprecise because the investigator is forced to choose from a small number of available stages, and each stage will have a relatively wide time interval associated with it because the sum of the stages must cover the entire postmortem period. Estimates of time since death for unidentified cases are, as a result, broad."

Unfortunately, despite the rather continuous nature of decomposition, anthropologists have taken a qualitative approach to describing the process, utilizing discrete, broad stages more out of convenience than precision. However, given the call for improvements in quantitative methods by various federal mandates, new approaches to modelling decomposition have been developed, leading to a more precise, accurate, and valid set of approaches toward estimating the post-mortem interval.

Describing Decay: Few, Broad, and Discrete versus Multiple, Specific, and Continuous Stages

Given the failure to understand the complex, multivariate system at play during decay, forensic anthropologists have often relied on a few, broadly-defined set of stages to describe the decomposition process. Beginning with Reed (1958) and continuing with Rodriguez and Bass (1983), the qualitative approach to decomposition has utilized a four-stage blueprint composed of fresh, bloated, decay, and dry phases (see Table 1). Each category presents the "typical" decompositional changes that occur, and more importantly, are portrayed as discrete stages. The decay process is made to appear categorical in nature, with the decompositional changes of a body essentially "jumping" from stage to stage (Nawrocki 2011: 2). Given the fact that the plethora of changes which occur over a body during decay are condensed into four or five stages with wide-time intervals, it is no mystery why estimates of time since death have been so imprecise.

Additionally, a few caveats are typically tossed in stating that environmental variability can alter these changes as well, without providing any quantitative understanding of how or why this is so. Essentially, the party line goes something like this: "Typically, 'X' number of days are needed to reach the decay stage. In the presence of higher temperatures, that number is driven lower." The lack of understanding regarding exactly how a particular variable affects the rate of decomposition, coupled with the inability to quantify how specific decompositional changes are related to time, produces imprecise intervals and "best guess" estimates that would frustrate any seasoned forensic anthropologist. However, when one moves away from a typological approach towards a semi-quantitative strategy and truly analyzes the decay process as it really takes place, it becomes clear that decomposition is not so discrete, and instead proceeds through a series of small changes which accumulate over time.

Recognizing the need for a more precise manner by which to estimate the post-mortem interval, Megyesi et al. (2005) devised a method to calculate total body score based on detailed descriptions of decomposition (see Tables 2, 3, and 4). More importantly, their strategy was designed to reflect the fact that decomposition is more continuous than discrete, and certainly better understood through a number of specifically defined-stages rather than a few broad categories. In total, they argued that the widths of time intervals associated with an estimate are inversely proportional to the number of stages available, or put more simply, systems with more categories offer higher precision than those with fewer categories (Nawrocki 2010). Thus, if seeking to reign in the imprecision of traditional PMI estimation methods, one needs to analyze the decomposition process as it actually occurs, as a continuous process, and provide a detailed set of stages by which to score the decomposition of a body.

Traditional Descriptions of Decomposition versus Total Body Score

Recognizing the disparity between traditional qualitative descriptions and the need for a more precise method by which to estimate time since death, Megyesi et al. (2005) modified the set of descriptors developed in Galloway et al. (1989), to devise a method to calculate total body score based on detailed descriptions of decomposition. Essentially, they were able to devise a system by which to allocate points to specific decompositional stages (see Tables 2, 3, and 4). Based on the stage in which the body is found, it receives the appropriate score. By quantifying the observed decomposition, it could then be divided by either post-mortem interval days or accumulated degree days to form a measure of the rate of decomposition.

This approach is in stark contrast to the way that decomposition studies were conducted in the past. Before the paradigm shift toward more quantitative-based studies, qualitative descriptions of decomposition were "correlated" to time (see Table 2). However, these "correlations" had no quantitative backing, as they relied mostly on observation, experience, and anecdotal evidence. In order to determine the time ranges during which a decompositional stage typically developed, one would simply note how long it would take for the fastest case to enter a particular stage, as well as how long the slowest case would take to progress to that same point. No quantitative analysese to determine the factors which produced such variation were conducted. Due to the fact that the decompositional stages employed were not assigned points or quantified in some way, there was no way to demonstrate how a particular variable affected the rate of decomposition over time.

Fortunately, Megyesi et al. (2005) were able to devise a method by which the presence or absence of a variable could be measured against the total body score over PMI or ADD. This measure could then be used to assess the impact of the variable on the rate of decay. In the traditional approaches, the lack of a total body score precluded measurements regarding the rate of decay due to the fact that it was not possible to develop a rate by dividing a qualitative description over a quantitative figure.

Where Megyesi et al. (2005) fell short, however, was by assuming that their total body score descriptions, i.e. the pattern of decomposition, were applicable across regions and in all environments. Given the stated impact of multiple variables on decay, whose effects are reflected in the decompositional changes observed on a body, the particular pattern of decomposition observed in one region will likely not hold true for that observed in another. Therefore, a specific qualitative analysis of the pattern of decomposition as it applies to the Delaware River Valley is needed, so as to derive total body score descriptions based on the pattern of decay seen in this region. Additionally, the skeletonized phase of the total body score needs to be elaborated, with this being a problem highlighted by Nawrocki's own admission that more specific decompositional stages are needed. By taking this approach, the time since death estimates derived from an equation will be more accurate, and rely on a total body score description which fits the pattern of decay in the region it is being employed. However, to achieve these goals, one must move away from the tendency to view decomposition as dependent on time, and instead realize the profound effect of temperature on decay.

Post-Mortem Interval Days (Time) vs. Accumulated Degree Days (Time x Temperature)

Traditional approaches to estimating the period over which an individual has been deceased have utilized qualitative descriptions of decomposition which have broken down into a few broad stages with wide time intervals, defined by the presence or absence of specific decompositional indicators (Nawrocki 2011). However, the focus on "time," reflected as a prediction of the post-mortem interval, and its supposed relationship to chemical and biological processes, bacterial reproduction, and insect growth, has caused forensic anthropologists to move away from explaining the effects of external forces on decay. Despite the fact that the relationship between variables such as ambient temperature and insect growth have been known since the 1940s (Davidson 1944), forensic anthropology has focused more on the end-point (PMI), rather than modelling the complex environmental system in which decomposition occurs (Nawrocki 2011). Put more simply, the field has focused more on the relationship between single pairs of variables than on multivariate tests and the networks of variables at play. Instead of conducting holistic research, isolating variables and measuring their actual effects, forensic anthropologists have skipped immediately to time since death predictions, without acknowledging the factors that have led to that final stage. As a result, estimates of PMI are wide and unnecessarily imprecise, and focus on defining the end product through the use of qualitative descriptions and a typological approach, rather than developing a nuanced and quantitative understanding of the factors at play. Ultimately, decomposition studies in forensic anthropology have been mired in approaches characteristic of the "dark days" of anthropology, rather than stepping into the new quantitative paradigm of today.

Given forensic anthropology’s focus on description rather than real understanding, the known relationship between ambient temperature and chemical and biological processes, bacterial reproduction, and insect growth, has largely been ignored. In fact, the emphasis in decompositional studies has been placed in the wrong area, focusing too heavily on time and not enough on the wide-reaching effects of temperature. As ambient temperature increases, chemical and biological reactions become more rapid and accelerate decay, whereas decreasing temperature decelerates the decompositional process. The specific link between temperature and the rate of decomposition is reflected in Van’t Hoff’s Law, which states that the speed of chemical reactions increases two times or more with each 10 degree C rise in temperature (Vass 2011). In fact, forensic entomologists utilizing the successional patterns and stage of development of insects to estimate time since death have been aware of this principle for years, and used them to make relatively precise estimates of time since death during the early post-mortem period (Nawrocki 2011). Their particular approach tabulates the number of heat-energy units available to drive chemical and biological processes, such as bacterial replication and larvae growth, measured as “accumulated degree days (Megyesi et al. 2005).” To make this calculation, the effects of time and temperature are multiplied (in theory), being calculated by summing the average temperature in an area over a specified time interval. Thus, if a body had been exposed to one 20 degree Celsius day, followed by another 30 degree Celsius day, the total accumulated degree day (ADD) load would be 50 ADD.

The most important point to make regarding the use of time and temperature to estimate time since death is that multiple studies have clearly demonstrated that the relationship between accumulated degree days and insect growth is stronger than the relationship between time elapsed and growth (Megyesi et al. 2005; Carter et al. 2007; Michaud and Moreau 2011). The main reason for this particular distinction is the fact that simple time elapsed does not account for the variation in temperature that has been known and proven to drive the processes involved in decomposition and decay (Nawrocki 2011).

To provide a more intuitive explanation of the importance of both time and temperature to decomposition, a simple analogy may be used: When estimating the amount of sharpness of a knife, it is not important to calculate the number of days in which the knife has been sitting in the knife block, but rather the number of cuts to which the knife has been exposed. The knife could have been sitting in the block for the entirety of its existence and not experienced any wear. Thus, when applying this analogy to developing a formula for determining how long an individual has been deceased, it is not important to simply correlate observed decompositional changes (i.e. sharpness) with the number of days in which the body has been exposed to the environment (i.e. sitting in the knife block), but rather the number of degrees to which the body has been exposed to (i.e. the number of cuts). Given the fact that temperature is known to drive the chemical and biological processes known to alter decay, capturing the total effect of temperature on a corpse will explain more of the variation involved in decomposition than a simple calculation of time elapsed.

In practice, one would be able to use an ADD formula to produce an estimate of the total accumulated degree days which have passed since an individual's death, and simply add the average temperatures from the day of the body's recovery back in time until that ADD total is me. This estimated would therefore identify the number of days since the individual’s death. As such, it not only incorporates the effect of heat-energy units on decay, but will also provide a more accurate estimate of how temperature influenced the post-mortem period.

Lastly, as hypothesized by Adlam and Simmons (2007), the use of accumulated degree days to jointly document time and temperature in decomposition studies allows the comparison of studies across environments. Prior to this advancement, the principal difficulty in understanding the decomposition process was the inability to directly compare results and observations from published research (Simmons et al. 2010a). These studies not only varied with regards to their methodology, but also the environment, species observed, and duration of the experiment. Some studies were longitudinal and laboratory-focused (Tibbett et al. 2004) and others were based on untested case studies (Rodriguez and Bass 1983; Mann et al. 1990), while some took on retrospective, cross-sectional approaches (Megyesi et al. 2005). In the end, these differences made it nearly impossible to draw clear conclusions from different studies (Simmons et al. 2010a). However, by standardizing the time/temperature relationship, experiments can be placed on an equal footing, at least with respect to accumulated degree days. Furthermore, the results of one study can be compared to those in separate regions and judged for their accuracy. Still, although advancements in estimations of ADD have been made, the standardized collection of the remaining variables known to alter the rate of decomposition has yet to emerge.

Region-Specific versus Universal Continuities

Given the obvious importance of capturing the effects of temperature on decay, the next logical consideration is whether or not additional environmental, scene-specific, and depositional variables should be collected to increase the precision of post-mortem interval formulas. Multiple studies have identified links between the rate of decomposition and variables such as insect and carnivore activity, trauma, exposure to the sun or shade, and clothing. By extracting these key variables from case records in real-life scenarios and developing models to measure their individual effects, researchers can begin to truly evaluate the complex environmental factors altering decomposition. When the results of these studies are combined with the obvious differences in the rate of decay between contrasting environments (see Galloway et al. 1989 versus Komar 1998), it becomes clear that it is necessary to develop decomposition formulas in multiple climatic and environmental regions throughout the country, in order to evaluate if region specific time since death equations are needed.

Conversely, some researchers argue that, instead of attempting to identify unique patterns of decomposition in different regions, forensic anthropologists should instead be searching for underlying continuities that help understand decomposition around the world (Simmons et al. 2010a). As stated by Nawrocki (2011), local variations are points along a continuum caused by small fluctuations in a few key variables such as temperature, humidity, etc. As such, these differences are not essential, and likely grade into one another. Given this school of thought, region-specific standards are not warranted, instead calling for global or universal formulas to be developed.

However, in Megyesi et al. (2005: 9), a study in which Stephen Nawrocki himself played a large role, future studies are urged to go beyond a simple evaluation of ADD and decomposition, and instead evaluate the effects of a number of additional factors.

> "Each of these variables could be measured and analyzed for their effect on decomposition, being incorporated into the regression equation if significant…Future research should also concentrate on narrowly defined regions of the United States in order to produce equations that are best tailored to a particular environment."

This assertion is a common theme in decomposition studies, with multiple researchers urging research in a variety of environmental regions, as well as the analysis of additional ecological factors. Therefore, although accumulated degree days should not have unique effects in different locations, bioecological variation, such as regional and seasonal differences in the activity of insects, carnivores, and any other factors that involving access to the remains, certainly may. Given this statement, before attempts to evaluate the necessity of region-specific equations are abandoned, it is important that studies such as these are conducted to assess whether variables beyond temperature have a significant effect on decay. Should this be the case, it may point to the need to move away from universal continuities and towards the generation of area-specific equations to better track local environmental and climatic conditions.

Core versus Periphery Processes

According to Nawrocki and Latham (2013), total body score can only be used effectively when modelling "normal" decay, as deviations are believed to introduce error. Normal decay processes involve systemic "core" variables and processes which drive decomposition and are linked to and dependent on temperature, such as enzyme activity, cell autolysis, bacterial replication, insect growth, and other such microorganisms (Nawrocki and Latham 2013: 455). On the other hand, alternate pathways such as adipocere formation, skeletonization, burning, and excessive carnivore activity, make up stochastic "periphery" variables which lead to atypical decomposition and are therefore too difficult to model (Nawrocki and Latham 2013: 455). If they are included in regression equations, Nawrocki and Latham (2013) argue that they will skew the resulting data, introducing confounding factors and error into the prediction process. Thus, given the purported systematic mathematical relationship between accumulated temperature and decay, Nawrocki and Latham (2013) state that time since death estimation methods must rely on those "core" processes. In fact, in their study on the use of accumulated degree days to estimate the time since death, Megyesi et al. (2005) regarded the impact of temperature on decay so highly that they set out to evaluate its singular role, compared to post-mortem interval days, in explaining the largest proportion of variation in decomposition. In the end, they incorporated TBS as the only independent variable in their time since death equation used to predict accumulated degree days. No other variables were analyzed for the percentage of variation in decomposition they may explain.

However, one of the benefits of conducting a multivariate regression analysis is that the effects of variables can be selected for based on the value of their coefficients of determination. Therefore, if there is the potential to accurately extract data regarding these "periphery" variables, those variables, which may contribute in a statistically significant manner to the explanation of a large proportion of the variation in estimates of time since death, can be analyzed. By controlling for other factors, single variables can be assessed for their impact on the rate of decay, being identified as significant or not significant by simple t-tests.

In addition, given the fact that Megyesi et al. (2005) deliberately excluded buried and submerged cases (assumedly due to the number of "periphery" variables involved in both contexts), it may be possible to compare the percent of variation explained in a time since death formula incorporating multiple depositional contexts versus formulas derived specifically for each type of depositional environment.

Lastly, given the significant role played by insect activity, carnivore access, and other factors that are known to accelerate decomposition, factors beyond total body score and ADD must be assessed (Simmons et al. 2010b). In fact, Nawrocki and Latham (2013) themselves state that post-mortem interval estimates can be informed by "peripheral" processes. Although these processes might not explain the same percent of variation in estimates of time since death as those driven by temperature, or be as cleanly modelled, they still require study. Therefore, if the ultimate goal of decomposition studies is the most precise estimate of time since death, given the call for studies in a variety of environmental conditions and regions, coupled with the potential effect of bioecological variation on decomposition, it is absolutely necessary to study the effects of both "core" and "periphery" variables, an approach this dissertation research study has taken.

Need for Quantitative Studies Employing the Use of ADD and Specific Descriptions of the Pattern of Decomposition in the Delaware River Valley

Most importantly, despite the results of multiple studies demonstrating the relationship between time and temperature, coupled with its introduction to human decomposition research by Vass and colleagues in 1992, forensic anthropologists have still been very slow in accepting the standardization of time/temperature, reflected as accumulated degree days, as the x-axis event timeline for decomposition (Simmons et al. 2010b). In fact, despite all of the benefits described above, some of the most current publications have still yet to incorporate the principle of accumulated degree days into their research designs or analyses (Magnanti and Williams 2008; Sharanowski et al. 2008; Bunch 2009). Moreover, it appears there is a general reluctance to accept the implications of results generated by its use (Simmons et al. 2010b).

Overall, decomposition studies continue to be plagued by the focus on time rather than its relationship to temperature, with estimates of PMI, and therefore medico-legal investigations, suffering as a result. Fortunately, in order to solidify the importance of ADD and end the debate regarding its applicability to decomposition estimates, this study seeks to demonstrate the effectiveness of the accumulated degree day principle for explaining the variation in decomposition observed in the Delaware River Valley, as compared to simply using the traditional summation of post-mortem interval days. When this focus is combined with the assessment of the decompositional pattern as it pertains to this specific area, and thus the development of a total body score system appropriate to the Delaware River Valley, it is hoped that estimates of time since death will be more in-tuned with the factors inherent to this particular environmental region.

Chapter Five: Review of Environmental, Scene-Specific, and Contextual Variables Believed to Alter Decomposition

In 1990, based on observations and experience gained through years of analysis at the Anthropology Research Facility in Tennessee, Robert Mann and colleagues were able to develop a subjective criteria rating on a five-point scale of the key variables affecting the rate of decay of the human body (see Table 6). With five being the most influential, three main factors were described as having the most bearing on progression of decomposition: temperature, access by insects and burial type/depth. The next most important factors were ascribed values of four, which included carnivore/rodent activity, as well as trauma and the amount of humidity. An additional three variables were determined to have a slight effect on decay, including rainfall, embalming, and body size and weight. Clothing was given a value of two, while the surface the body was placed on was deemed the least influential of all factors. Soil pH was identified as a potentially important variable as well; however, its effects were still in the process of being studied at the time the paper was published. Since then, the effects of soil acidity have been shown to participate in the destruction of organic remains as well (Surabian 2011).

Given the identification of these key variables, subsequent experimental and actualistic studies in various regions and climates have followed suit, evaluating the variables and criteria highlighted in Mann et al. (1990). These studies were designed in an attempt to assess the roles played by these factors and determine if these variables are in fact inextricably linked to altering the rate of decomposition (Rodriguez and Bass 1983; Rodriguez and Bass 1985; Galloway et al. 1989; Komar 1998; Parks 2011; Ross and Cunningham 2011; Vass 2011). Given this call, multiple factors have been identified as critical to the rate of decomposition including temperature, moisture, pH, and the partial pressure of oxygen (Vass 2011). Temperature itself has been inextricably linked to other variables such as insect and scavenger activity, seasons, altitude, latitude, burial depth, presence of water, air movement, vegetation, wrappings, clothing, and so forth (2011). Even in the infancy of decompositional studies, the "father" of taphonomy, I.A. Efremov (1940: 83), recognized these relationships stating, "the passage from the biosphere into the lithosphere occurs as a result of many interlaced geological and biological phenomenon." Therefore, by studying the relative impact of the aforementioned factors on the decay process through both controlled and multivariate studies, these research efforts have aimed to match up those variables with observed decompositional changes and known time since death periods, to develop standards for assessing the post-mortem interval in these specific regions.

Given the fact that ambient temperature appears to have the greatest influence over the decay process, guiding the degree to which other variables impact decomposition, and because variability in decomposition is the "rule," Mann et al. (1990: 110) make it clear that it is "imperative that further research be conducted…in many other states where temperatures and other environmental and ecological factors differ from those in east Tennessee." Therefore, by having data specific to the conditions in a particular region, one can also begin to assess whether region-specific standards are needed in order to ensure the validity and reliability of PMI estimates for application in actual forensic cases. Given the lack of research in the Delaware River Valley Region, the need to validate previous claims and research in other climatic conditions is obvious.

Furthermore, by gathering information related to the relative impact of environmental and scene-specific variables on decomposition, research efforts can begin to illuminate questions regarding the most influential factors on decay and whether those variables can or cannot be separated apart, ultimately guiding the development of formulas used to estimate time since death.

Lastly, Mann et al. (1990) make it very clear that their criteria and rating scale are based on subjective judgments developed through years of research and experience at the University of Tennessee. Although experience has played a vital role in qualitative assessment of time since death in the past, if the field seeks to progress into the new quantitative paradigm, studies need to move away from subjective evaluations towards more statistically-supported conclusions. Clearly, this gap in objective evaluation warrants further examination.

Therefore, in total, by illuminating the relationships between these variables, as well as conducting multivariate regression analyses in climates as of yet unstudied, this dissertation research can develop a means by which to objectively evaluate the variables altering the rate of decomposition and create standards specific to the Delaware River Valley region.

By gaining insights into the factors at play, one can hope to begin to piece together the puzzle which is time since death determination. The following section attempts to do just that, highlighting multiple variables identified throughout the years as influencing the rate of decay in one form or another, as well as the current research and schools of thought regarding the roles they play in altering the rate of decomposition.

Temperature

The most important factor influencing the speed of decomposition has been determined to be temperature (Mann et al. 1990; Gill-King 1997). In fact, thermal load over time, measured as accumulated degree days, is believed by some to account for the greatest amount of variation seen in decay (Megyesi et al. 2005). This particular phenomenon explains why the breakdown of tissues is quicker in hot climates versus cold environments. Moreover, it has even been demonstrated how elevated temperatures in the body at the time of death, such as through fevers, placement next to heaters or under electric blankets, immersion in hot water, and so forth, functions to optimize bacterial growth and accelerate decomposition (Zhou and Byard 2011).

Importantly, temperature has been demonstrated to be interrelated with a number of factors known to alter decomposition, ultimately guiding the speed at which the decay process progresses. Its affects are far-reaching, influencing many of the variables known to impact decomposition and soft tissue breakdown including insect activity, the presence of carnivores and rodents, decay in specific depositional environments, and so forth. Although claims have been made that insect activity is the most important variable in regards to the rate of decomposition (Simmons et al. 2010a; 2010b), without an optimal range of conditions guided by temperature, insect activity can be greatly retarded or halted altogether. Therefore, without knowledge of the temperatures and climatic environment to which a corpse has been exposed, not much can be said regarding time since death.

Temperature and Soft Tissue Breakdown

Common sense dictates that the warmer the temperature, the quicker soft tissue will decompose. The inverse applies to cold environments. In fact, autolysis is temperature dependent, slowing under cool conditions (Clark et al. 1997). Under arid conditions, bodies have been known to completely skeletonize within a matter of a week (Galloway et al. 1989). In the same region, it was observed that reduction to skeletal elements during the winter was accomplished in five times the time required during the summer (1989). As a matter of fact, studies have been conducted examining decay rates in both hot and cold climates, with research in such areas as Arizona (Galloway et al. 1989) and Texas (Bucheli et al. 2009; Parks 2011), as well as Edmonton (Komar 1998) and the Yukon Territory (Bygarski and LeBlanc 2013), confirming these assumptions.

As noted above, an important point to make here revolves around the relationship between desiccation and putrefaction. Immediate post-mortem change is a competition between the two, with external factors such as temperature, and the related phenomena of humidity and aridity, largely determining the outcome (Micozzi 1997). Desiccation, whether through aridity in hot climates or freeze-drying in the cold, can preserve remains. Given the drying out of tissues which accompanies desiccation, insect activity can be greatly retarded, requiring moisture in order to oviposit eggs (Haskell et al. 1997). Putrefaction on the other hand operates in the presence of moisture and moderate temperatures, as it is guided by bacterial action (Micozzi 1997). Decomposition taking place in an environment with temperatures between 60-95 degrees F will be rapid, as bacterial growth and cell division occur best under these conditions (1997). During such temperatures, desiccation of tissue must be rapid if any preservation of the soft tissue is to take place (1997). However, once temperatures begin dropping below the optimal range for bacteria, bacterial reproduction becomes greatly retarded, eventually stopping altogether (1997). As temperatures continue to fall, the degree of desiccation required for preservation becomes reduced. In fact, between 32-41 degrees F, bacterial multiplication ceases and insect activity becomes greatly retarded, as freeze-drying through desiccation becomes the best preservative technique (1997). In temperatures below freezing, insect activity stops altogether (Mann et al. 1990). At higher temperatures, boiling may kill bacteria but conditions do not reach that stage. Instead both desiccation and bacterial growth occur more rapidly, with the outcome depending on the relative humidity (Micozzi 1997). Under conditions of high aridity and low humidity, skin and internal organs will rapidly dehydrate, creating a natural buffer against insects, in some cases leading to mummification (Mann et al. 1990). Thus, the intricacies of decomposition demonstrate the impact multiple variables have on each other. Given the interrelatedness among all of those factors, one must be rigorous in accumulating data on all relevant variables, especially temperature, or else risk inaccuracies in estimating PMI.

Temperature and Humidity/Aridity

Given the importance ascribed to levels of humidity and aridity by Mann and colleagues (1990), and its definite association to the crucial variables of temperature and precipitation level, it is clear that both humidity and aridity play huge roles in altering the decomposition process.

Aridity rapidly dehydrates skin and internal organs, creating a natural buffer against insects and other organisms, in some cases leading to mummification (Mann et al. 1990). These tissues may show very little destruction by insects due to the need for fly eggs to be deposited in areas of moisture and protected from direct solar radiation (1990). Even under cold and dry conditions, bodies have been known to mummify, retaining much of the skin for years after death. One need only look at the effects of glacier entrapment on Ötzi, the Tyrolean Ice Man (Dickson et al. 2003), or Kwäday Dän Ts'ìnchí (Long Ago Person Found) (Dickson et al. 2004) to realize the preservational effects of cold and dry temperatures. In addition, the work of Micozzi (1986; 1997) further highlights the effects of freeze-drying which, coupled with cycles of thawing, produces a faster disarticulation rate in animals compared to fresh kills due to the disruption of tissues.

Of course, increased humidity on the other hand, is correlated with an acceleration of the rate of decay, due primarily to the increase in bacterial action and fly and maggot activity (Mann et al. 1990). Besides providing more favorable conditions for insects to operate under, humidity also slows the drying of soft tissue, allowing for ease of consumption by insects. If flies are provided with proper conditions to oviposit and larvae are capable of feeding, corpses will break down fairly quickly.

Temperature and Insect Activity

Given the importance of insects to the deterioration of the tissues of the body and thus assessments of post-mortem interval, the relationship of temperature to insect activity must be explored. Without an understanding of temperature's effect on the growth and development, as well as the feeding and successional patterns of insects, determinations of time since death are relatively meaningless.

In order to fully understand the role played by insects on decomposition, the effects of temperature on their activities must be understood. Flies are poikilothermic, meaning they are cold-blooded, making their temperatures highly influenced by the conditions of the surrounding environment (Haskell et al. 1997). Flies tend to operate most efficiently within a maximum and minimum temperature range, visiting a carcass and laying eggs in conditions as cold as the mid-40s degrees F (Mann et al. 1990). Temperatures dropping below this, especially past the freezing point, can kill both fly eggs as well as maggot larvae if left exposed to the environment. In fact, a study evaluating the most effective PMI estimation techniques noted that the freezing point is the lowest developmental threshold for insects, with PMI estimates decreasing in precision when the developmental threshold was raised (VanLaerhoven 2008). This explains the phenomenon of how a body left frozen on the surface can remain untouched for months, as the lack of blowflies, coupled with the unwillingness of insects to process the corpse, will allow the body to progress unaffected until thawing (Haskell et al. 1997). If able to gain access to the inside of body cavities however, maggots can generate their own heat, sustaining them as they feed on the corpse (Mann et al. 1990).

At the other end of the spectrum, adult fly females require adequate moisture and protection from direct solar radiation in order to lay their eggs, so as to not create an inhospitable environment for the larval stages (Galloway et al. 1989; Haskell et al. 1997). Temperatures constantly above 85 degrees F have been observed to deeply alter the life cycle of blow flies, producing stunted larval forms which fail to pupate and eventually die (Wigglesworth 1967; Queiroz de Carvalho 1996). Thus, if conditions are too hot and arid and drying out the tissues occurs, external maggot activity in early decomposition may not take place. This explains the phenomenon of how skin can be left completely intact in the case of mummified remains. Within the bounds of hot and cold extremes however, the development of insects has been measured to proceed at a more rapid rate as temperature increases, with their rates of development being measured at various temperatures to allow a prediction of the time required to reach the observed stage (Haskell et al. 1997). As long as conditions due not reach those leading to mummification of the skin, hot temperatures are quite favorable for insect activity. Therefore, it becomes quite clear that the accumulation of weather records specific to an area, coupled with an understanding of temperature's effects on insect activity, is crucial to developing the narrative surrounding PMI estimation.

Additionally, Reed (1958) found that although the total insect population was greatest during the summer, some species reached their population peaks during cooler times of the year. Thus, if the remains of such insects were to be discovered accompanying the corpse, insights into the time of year death occurred may result. Clearly, the importance of temperature to insect activity continues to be made obvious.

Furthermore, as it applies to aquatic environments, water temperature can play an important role in minimizing the impact which aquatic insects have on decomposition. In fact, temperature and water currents are two of the main factors affecting the rate of breakdown of a corpse in this context (Anderson and Hobischak 2004; Haefner et al. 2004; Zimmerman and Wallace 2008). Given the low temperatures characteristic of water throughout many months of the year, maggot mass activity on a corpse can become greatly retarded. With greater exposure to wave action and deeper water, oviposition decreases, lower levels of maggot mass activity develop, and internal carcass temperatures drop (Davis and Goff 2000). As a direct result, the influence of insect activity on decomposition decreases. The impact is such that Merritt and Wallace (2001) and Wallace et al. (2008) caution against the use of aquatic insects in the estimation of the post-mortem submersion interval (PMSI).

Lastly, an interesting argument was posed by Simmons et al. (2010b) regarding the role played by insect activity in decomposition. Their study was constructed as a comparison of the decomposition rate of rabbits either buried after exposure to insect activity, buried without exposure, kept above ground behind an insect screen, or continuously exposed above ground (2010b). Dipteran oviposition was only observed in the groups buried after exposure to insect activity and those continuously exposed above ground (2010b). Decomposition rates were measured by total body score at 50 accumulated degree day increments. The results showed no difference between rabbits kept behind the screen and those buried without exposure (2010b). This rate was significantly slower than those buried after exposure, which was in turn, significantly slower than those continuously exposed (2010b). Given the fact that those groups with no insect exposure decomposed much slower than those exposed to insect activity, coupled with the quicker rate of decay seen in continuously exposed remains versus those buried after exposure, they conclude that insect presence is the primary agent affecting the rate of decomposition (2010b). These results correlated with their earlier findings, which suggested that regardless of indoor, buried, or submerged contexts, the greatest effect on decomposition rate was the presence or absence of insects (Simmons et al. 2010a).

Their specific thought process relates to the fact that buried remains tend to exhibit little to no insect activity, depending on depth (Rodriguez and Bass 1985). Therefore, this would account for the slower decomposition observed between the surface deposition and the carcass buried after exposure. The other two contexts lacked any insect activity and displayed a much slower rate of decay, supporting their claims regarding the role played by insects. Additionally, these results are in line with a previous study conducted by the same authors which concluded that no significant differences exist in the rate of decomposition of carcasses in water, buried, or left indoors (Simmons et al. 2010a). In total, they reason that insects have the highest influence on the rate of decomposition compared to any other variable.

However, several considerations should be noted in regards to their logic. By demonstrating the fastest rate of decay to be represented by the carcass on the surface and the slowest by the carcass protected by an insect screen, they mean to point out how when temperature is essentially controlled for, insect activity plays the most important role in the rate of decomposition. This logic is flawed in the sense that should the temperatures have been below the freezing point, no insect activity would have been observed. In fact, in a study conducted by VanLaerhoven (2008) evaluating various PMI estimation techniques using accumulated degree days, the most precise techniques employed the use of zero degrees C as the lower developmental threshold. As the lower developmental threshold increased, PMI interval estimates increased as well (2008). Thus, as it is applies to time since death estimates, temperature is a primary factor. Considering the inverse, as demonstrated by Haskell et al. (1997), should the temperature have been so hot and dry that all tissues rapidly desiccated, insect activity would also have been greatly reduced. In these particular examples, insect activity would be completely dependent on temperature. With that being the case, temperature has to play the most important role overall.

Most importantly, they justify their conclusions by utilizing a perspective which alters the particular role played by temperature. In order to do so, they qualify their statement regarding the central role played by insect activity by saying this is only so when time and temperature are standardized using accumulated degree days (Simmons et al. 2010b). In effect, they acknowledge the importance of sufficient thermal energy to progress through the stages of decomposition, but upon standardization, they essentially reconfigure its role in estimating time since death. In essence, they recognize how temperature affects decomposition on its own, but by standardizing time and temperature and making accumulated degree days the variable to be predicted, insect activity is left as the primary agent in decomposition, whose effects are reflected in the total body score. This new approach removes temperature as a variable used to explain the decompositional changes observed in relation to time, and instead combines it with time to become the unit to be predicted, i.e. ADD. Thus, overall temperature is still the guiding force in decomposition, but when standardized to become the dependent variable, insect activity is shown to play the central role in the rate of decay.

Temperature and Carnivore/Rodent Activity

As stated by Mann and colleagues (1990), the scavenging of remains by carnivores and rodents can significantly contribute to the processing of a corpse. Much like insect activity however, the scavenging process is inextricably related to the effects of temperature. To begin, the relative freshness of soft tissue appears to play a role in its desirability by animals. Haglund (1997) provides an example of this, claiming that “wintered over” or saponified remains seem to be of less interest to canids. In the same vein, a study conducted on gray squirrels demonstrated that the rodents only began gnawing on bone after fats had leached away (Klippel and Synstelien 2007). Given the ability of temperatures to dry out remains, warm or cold climates may alter the time required to observe evidence of rodent activity. In addition, gray squirrels took longer to process remains left to decompose in shaded areas compared to those left in full sunlight (2007).

Furthermore, the season of the year affects the social behavior of potential scavengers as the availability of food and competition for resources directs group size and aggressiveness, potentially lowering or eliminating evidence of damage depending on seasonal temperatures (Haglund et al. 1988). Given the potential reduction in carnivorous activity during colder periods, especially amongst those animals which hibernate, remains may be preserved to a greater extent (1988). The social behavior of coyotes is also affected by the season of year, due in part to the seasonal nature of food sources. In summer, since coyotes are able to sustain themselves on rodents, they tend to be less social, compared to winter months when food source availability fosters the ability to sustain larger group sizes (Beckhoff and Wells 1980). Overall, it appears that this trend can have a significant impact on the breakdown of a corpse, necessitating investigators to note the presence or absence of indicators of carnivorous activity, as well as the temperatures to which the individual may have been exposed.

Moreover, the impact of temperature on canid-assisted scavenging standards, which employ the use of observed disarticulation patterns, must be made clear. During warmer weather, carnivores need to compete for access to remains with insects. If scavengers are only able to locate a set of remains late on in the decomposition process after insects have begun disarticulating the corpse themselves, this can significantly modify the expected sequence of disarticulation by scavengers and the decompositional patterns seen. Thus, the effects of temperature are once again clear and obvious, demonstrating the necessity to gather climatic records in order to fully comprehend and interpret the process of decay seen at a site.

Carnivore/Rodent Activity

Scavengers, such as bobcats, rodents, pigs, raccoons, opossums, bears, dogs, coyotes, birds, amphibians, and reptiles, all play a large role in decomposition, breaking down soft tissues and processing skeletal elements (Morse 1983). In fact, at the University of Tennessee, 77.8% of surface cases showed gnaw marks indicative of scavenging (Willey and Snyder 1989). The extent of the role played by scavengers on decomposition depends in large part on a variety of factors, many of which have already been discussed. Temperature can affect scavenging through freezing of corpses for example. Burial depth and other forms of sheltering can prevent access to remains (Rodriguez and Bass 1985; Haglund et al. 1988). Human population density in the area also contributes to bone recovery and the extent of damage (Haglund et al. 1988). The freshness of tissue can guide its attractiveness to scavengers, while the condition of bony elements, whether “wet” or “dry,” can attract a certain set of rodents (Klippel and Synstelien 2007). Even order of access to remains can affect the placement of tooth mark artifacts on bone, producing differential patterns of alterations to the skeleton as specific species prefer particular areas of bone over others (Haynes 1983; Haglund et al. 1988).

Most importantly for estimations of the post-mortem interval, the extent of animal chewing and disarticulation has been determined to be one of many factors known to play a role in the variation seen in the rate of decay (Mann et al. 1990). Fortunately, researchers such as Haglund, Willey, and Snyder (Haglund et al. 1988; Willey and Snyder 1989; Haglund 1997) have been able to document the stages of the sequential alteration of human bone remains by canid scavenging, associating them to an observed post-mortem interval range. Even vultures have been observed processing and disarticulating remains in a patterned way (Reeves 2009; Dabbs and Martin 2013).

Based on a study conducted by Willey and Synder (1989) assessing canid modifications of human remains and their implications for time since death estimations, it was observed that captive wolves feeding on road-killed deer consume flesh in a predictable sequence. The sequence is as follows: 1.) The first portions of the carcass inspected by wolves are those areas with broken skin and wounds, 2.) Meaty sections, followed by the thoracic cavity, and ribs are then consumed, 3.) Next, the throat is opened and the nose eaten, 4.) From there, the disarticulation of the forelimbs, followed by the hind limbs, occurs within 24-48 hours, 5.) Following that is the reduction of the limb bone, vertebral column, and rib ends, 6.) Lastly, remnants of the vertebral column and hide are consumed within 4-7 days. Additionally, porous long bone ends, such as the proximal humerus and both ends of the femur, are often destroyed, but thick compact bone ends, like the distal humerus and tibia, survive, with ribs and vertebrae often being destroyed and the bones of the hands and feet being swallowed. In total, when granted full, preferential access to a corpse, scavengers take 1-7 days to move the carcass, process the body, and break down, separate, and scatter the skeletal elements (1989). Based on this analysis, the study concluded that scavenging hastens physical decomposition (1989). In addition, the succession of insect species becomes more rapid, but the insect numbers and activity are reduced as the movement of the body forces the migration of insect habitats, inhibiting the laying of eggs. Insects, eggs, and larvae also become consumed in the process (1989).

However, there are several limitations to this study. Firstly, the wolves were held captive, meaning they were outside of their natural habitat and in a potentially foreign social structure which could have functioned to alter behavior. Secondly, the activity presented by the particular wolves used in the study may not be representative of all such wolf species throughout the country, especially when taking into consideration environment/regional-specificity, seasonality, pack structure, and so forth. Given the fact that they were held captive and subsequently introduced to the carcasses, this may also represent an unrealistic sequence of events, as they typically do not have preferential access to remains. A multitude of factors may be involved in food acquisition in nature, including how and by what time food is found in the wild, the number of competitors already present on a food source, and the tissues remaining on the body. All of these variables may work to alter the "typical" sequence observed. Lastly, although wolves are scavengers, they are but one set of animals who feed on remains. Thus, their activity cannot be generalized across the board. Despite these issues, an important point to note deals with the findings of previous studies who suggest that regardless of predator size, dismemberment sequences are essentially the same (Haynes 1981; Blumenschine 1986). Therefore, the sequence observed on the deer carcasses can be applied directly to canid-assisted human scavenging. Nevertheless, despite the applicability of such studies to humans, the fact remains that these processing sequences have been demonstrated to be extremely variable and area dependent (Haglund 1997; Dabbs and Martin 2013).

This final point is made even clearer when considering the potential impact of population density on the presence or absence of animal scavenging. In areas with higher human population densities, it has been observed that relatively fewer scavenged human skeletons have been found (Haglund et al. 1989). This fact is consistent with the likelihood that in more inhabited areas, fewer animals exist and smaller group sizes can be seen (Haglund 1997). What's more, even if carnivorous scavengers were roaming about highly populated areas, remains are likely to be discovered before they are able to locate and process the body. Thus, considerations of corpse breakdown and processing must weigh the potential impacts of carnivorous activity not solely based on the presence of punctures or score marks, but also against the likelihood of scavenging given the particular area in which the body was recovered.

Insect Activity

The idea behind entomological determinations of time since death involves collecting species from the corpse, noting its stage of development, obtaining weather records from the area, and calculating how much time would be required to allow the insect to reach the stage seen (Haskell et al. 1997). However, the identification of insect stages must also be combined with an analysis of the relative amounts of various species.

In terms of number and presence, the orders Diptera (flies) and Coleoptera (beetles) are by far the most frequent colonizers of decomposing remains (Haskell et al. 1997). Blowflies of the family Calliphoridae, which are commonly recognized by their metallic blue and green colors as they swarm around garbage cans or dead animals, are the first insects to arrive at a corpse (1997). Interestingly, they have not only been observed on bodies within seconds of death, but they have also been seen to begin infestation prior to death (Davis 1928; Anderson and VanLaerhoven 1996; Haskell et al. 1997). This process first described early on by Davis (1928) and James (1947) is known as myiasis, and depends on the ability of the insects to find the body and the environmental conditions in which it has been deposited. Blowflies are divided into four major groups in North America, a few of which can be found in temperate climates (Haskell et al. 1997). Bluebottle flies are found during the spring and summer in temperate areas, while greenbottle flies can be encountered in midsummer (Hall and Haskell 1995). Black blowflies are found when moderate temperatures exist (1995).

Continuing on, although blowflies are usually among the first to colonize a body, carrion beetles begin to appear during the bloated stage, roughly two to three days after death (Rodriguez and Bass 1983). These beetles have been observed not only feeding on the decomposing flesh, but also on young fly larvae (1983). As time goes on and the progression through to the end of the decay stage and the beginning of the dry stage occurs, the beetles begin to outnumber the flies, eventually replacing all or nearly all of the fly species (1983). This particular distinction can be immensely useful for estimations of the post-mortem interval.

Moreover, Campobasso et al. (2001) were able to summarize cadaver microfauna, breaking them up into four main groups. The first category is composed of necrophagous species which feed only on decomposing tissues. These insects include Diptera and Coleoptera. The second group is made up of predators or parasites of the necrophagous species. The third category contains omnivorous species such as wasps, ants, and some beetles. These insects can feed on both decomposing remains and associated arthropods. Lastly, the fourth group is made up of opportunistic species such as Acari, spiders, and

Lepidoptera. Although these species can occasionally predate on the necrophagous species, they mostly use the corpse as an extension of their habitat. In regards to their importance to forensics, the first group is the most important while the last is the least important (2001).

As mentioned above, not only do insects help breakdown a body, but they can also be used to help determine time since death during the first few weeks following the death of an individual. When using entomological standards to determine PMI, two main methodologies are used to accomplish this task: a species' known developmental patterns and evaluations of insect successional waves (Haskell et al. 1997), although some claim the ability to age blow fly pupae through internal morphological analysis of pupae cross-sections (Davies and Harvey 2013). In fact, by understanding the life cycle of a specific insect species and the successful "waves" which aggregate onto a corpse, one can potentially be within 12 hours or less of the actual time since death, if the remains have been out for more than 15 to 20 days (Haskell et al. 1997). Although some claim its effectiveness up to a year after expiration, others state that entomological standards have been used on a corpse to calculate PMI up to 52 days since death (Amendt et al. 2004). Regardless, overall, compared to other PMI techniques, forensic entomology is relatively accurate and useful for up to several weeks after death. However, before entomological standards are applied across the board, as discussed in more detail in previous sections, it must be noted that the effects of temperature may alter life cycles and the successional pattern, especially if it delays access to the corpse or the development of the eggs and larvae.

Given the nature of this variable, it obviously depends in large part on the circumstances in which the deposition of a body has taken place, especially when considering the fact that insects respond directly to their environment. In fact, the number and type of insects present at a scene will vary depending on the area in which the remains are left to decompose (Anderson 2010). Bucheli et al. (2009) have already demonstrated how insect fauna in specific regions represent unique assemblages particular to their environment and time of year. In turn, although insect succession is a useful tool for determining the early post-mortem interval, it is precisely correlated with each geographical region (2010).

Thus, entomological studies have been conducted in many diverse contexts to determine the effects which different environments have on insects (Kelly et al. 2009). These studies include analyses of insect succession on pig and human remains in a variety of contrasting habitats including humid, subtropical (Payne 1965), arid (Galloway et al. 1989), subarctic (Bygarski and LeBlanc 2013), intertidal (Early and Goff 1986; Davis and Goff 2000), and water (Payne and King 1972; Hobischak and Anderson 2002; Wallace et al. 2008), as well as inside houses (Anderson 2011), buried (Rodriguez and Bass 1985), and exposed and shaded contexts (Shean et al. 1993), to name a few. In turn, a great deal of experimental knowledge has been gained regarding insect succession in these particular contexts.

What's also of critical importance to note here is that if the body is in an environment that prevents infestation, the process of decay will be greatly reduced (Mann et al. 1990). This is due in large part to the overwhelming majority of soft tissue breakdown resulting from feeding by insect larvae (1990). Thus, in closed environments such as sealed containers, bags, trunks, tightly wrapped bodies, etc. access to insects may be restricted, retarding the decay of a corpse. These specific circumstances and contexts not only produce variations in decay and the ability of insects to access a body, but they also affect scavenger activity, and the exposure of remains to climatic forces.

Furthermore, as will be shown below, differences exist in the rate of decomposition depending on the type of "burial" and its depth. For example, in aquatic contexts, only approximately eight of 13 orders of insects containing species which are minimally semi-aquatic are likely to be associated with corpses in aquatic habitats (Wallace et al. 2008). Given the considerable difference in the sheer numbers of terrestrial insects that have evolved functionally to feed on carrion compared to those in water, differences in decomposition are expected. Additionally, colonization by aquatic insects depends on a whole host of factors, not only including water temperature, but also size, texture, and position of the body, flow of water, current speed, depth, and the presence of aquatic flora and fauna (Sheldon 1983; Moran 1983; Tevesz 1985; Peckarshy 1986; Siver et al. 1994). Given the impact of tides, currents, and depth on aquatic insect access, as well as the variability inherent in the ability of aquatic insects to colonize a body, Wallace et al. (2008) warn that some precision is lost in estimating the post-mortem submersion interval with insects. Therefore, it becomes blatantly obvious that quantitative methods must be developed which not only account for the effects of insects on decay in aquatic contexts, but also the joint effects of a number of additional factors.

Another critically important point to consider is the ovipositing behavior of insect species. Currently, it is debated whether or not carrion flies are exclusively diurnal or oviposit at night (Stamper et al. 2009). What's more, mathematical models have been derived to estimate PMI from the developmental stage of larvae assuming diurnal oviposition (Byrd 1998). Given the possibility of up to 12 hours of additional activity about a corpse, this particular point of contention is crucial to decomposition analysis. However, despite the majority of studies establishing a diurnal pattern, Greenberg (1990), and Singh and Bharti (2001; 2008), have specifically identified flies actively flying at night. In particular, Greenberg (1990) reported nocturnal ovipositioning levels of 30% for blow flies, while Singh and Bharti (2008) reported 20% for flesh flies. Given the low sample sizes characterizing subsequent studies aiming to refute these claims, Stamper et al. (2009) set out to analyze the nocturnal oviposition behavior of carrion flies in Cincinnati, Ohio with a substantially higher total sample size. The study found that over the course of two consecutive summers, in both lit and unlit conditions, no nocturnal ovipositioning was observed on euthanized rats (2009). Importantly, they also failed to note any difference in regards to nocturnal ovipositioning between urban and rural locations (2009). Therefore, despite the variability in insect activity described above, it appears as if nocturnal ovipositioning does not occur, regardless of area.

Besides issues concerning variability in the diversity, composition, and activity of insect species, an additional four areas of controversy have been noted in regards to using insect developmental rates for estimating the post-mortem interval. The first area of concern revolves around whether or not maggot mass temperatures should be included into PMI estimation equations (VanLaerhoven 2008). As noted by Anderson and VanLaerhoven (1996), maggots feeding in a mass can increase temperatures on the body much higher than that of the ambient temperature. As a result, this may function to increase the normal developmental rate of flies. However, this claim is countered by observations concerning the migration away from corpses by the oldest maggots, prior to the elevation of temperature by the maggot mass (Dillon and Anderson 1996).

Secondly, despite the commonly held belief that the freezing point is the lowest developmental threshold in which different species of flies will develop, multiple studies have employed the use of higher thresholds (VanLaerhoven 2008). As summarized by Higley and Haskell (2001), despite the common use of zero degrees C as the lowest threshold for all blow fly species, some researchers utilize thresholds between six and 10 degrees C. However, these thresholds have only been supported for use in regards to the development of *Phormia regina* (Byrd and Allen 2001) and *Calliphora vicina* (Donovan et al. 2006), completely lacking experimental evidence for any other species.

Thirdly, there exists some variability in developmental data regarding a variety of blow fly species depending on the source used (VanLaerhoven 2008). Once again, as summarized by Higley and Haskell (2001), as many as 10 published studies exist providing developmental information; however, they all vary slightly in their data for the same species. As a result, variable PMI estimates can be produced depending on the source consulted.

Lastly, although the most commonly used method to calculate accumulated degree days involves a simple calculation of the average minimum and maximum temperatures each day, other methods exists (Higley and Haskell 2001). Once again, this slight difference may lead to variations in results (VanLaerhoven 2008). Care must be taken to be aware of the methods used by data sources in order to prevent unnecessary inaccuracies.

Still, in lieu of the potential uses of forensic entomology for the estimation of time since death, the application of these principles in a medico-legal setting is oftentimes impractical. Unfortunately, most forensic investigators and Medical Examiners lack detailed knowledge of insect species, as well as the ability to identify stages of development and successional patterns. In turn, forensic entomological analysis must be conducted outside of the confines of Medical Examiner's offices and forensic laboratories. Given the lack of monetary support for investigations into the dead, monetary issues often prevent such consultation. Therefore, despite the accuracy inherent in entomological analyses of PMI in the first few weeks after death, practical methods of determining time since death, which can be applied within medico-legal offices and labs, must be developed

However, regardless of the use of entomological standards, an understanding of temperature's effects on insect activity is crucial to developing the narrative surrounding PMI estimations, especially given their critical role in the decomposition process. If a corpse is denied access by insects due to temperature constraints, or other factors to be discussed below, time since death estimates can be severely thrown off. Thus, any PMI determination formulas to be developed must take into account insect presence, temperature, and the circumstances and environments to which a body has been exposed.

Depositional Environment

Decomposition rates depend on the extent of internal and external environmental factors on a decomposing body, as influenced by body disposal method (Gill-King 1997). Whether outdoor or indoor, buried or on the surface, submerged in water or left exposed to the elements, the context of body deposition is of critical importance to reconstructing time since death. Its affects are intricately linked to a number of important variables and can mean the difference between rapid decay or the preservation of remains. Based on the understanding that surface depositions are known to lead to the fastest breakdown of tissues, as remains are left exposed to the forces of nature, Maples and Browning (1994) surmised the relationship between decomposition in these contexts, equating one week on the surface to two weeks in water and eight weeks in a deep burial. This assumption has been used as a springboard throughout the years, as researchers have attempted to evaluate the validity of the statement and draw conclusions regarding the impact of depositional environment on decomposition.

Surface Depositions: Exposed vs. Shaded Remains

Although not directly singled out by Mann et al. (1990), researchers have long pondered the notion of whether or not exposure to direct sunlight versus shade impacts the rate of decay. These factors are of particular importance given their relationship to temperature, aridity, and insect activity, and the ability of these types of research questions to determine the applicability of decompositional standards in forested environments to bodies decaying in an open field. One study in particular uses pig carrion to evaluate the impact of those exact variables as they apply to coastal Washington.

Shean et al. (1993) placed two pig carcasses in close proximity to each other, one carcass was directly exposed to the sun, while the other was shaded in a woodland area. Carcasses at both locations attracted blowflies within 20 minutes of deposition, with ovipositioning occurring two to three hours later. When insects species were analyzed, it was seen that similar insects populated the corpses, but in different ratios (1993). In addition, the exposed pig demonstrated maggot mass temperatures higher than the shaded carcass (1993). Importantly, differences in the rate of decomposition were observed between both pigs, with bloating increasing more rapidly in the exposed pig, followed by a much quicker loss of weight (1993). Migrations of maggots were much larger and quicker in the exposed pig, as the shaded carcass demonstrated a more gradual, sustained migration (1993). In total, it was determined that the effect of increased temperature and direct sun exposure may stimulate maggot growth and activity, reflected in higher maggot mass temperatures and faster decay (1993).

An important point to note however, is that blowflies require moist environments to lay their eggs (Haskell et al. 1997). If carcasses face prolonged exposure to direct solar radiation, tissues may dry out quicker, leading to a quicker progression to the stages of mummification, sometimes leapfrogging the active decay phase for the dry decay phase. In turn, flies are less likely to oviposit eggs, as the conditions are not suitable for development. These occurrences are most dramatically seen in arid environments, where skin has been noted to be left virtually untouched in several instances (Galloway et al. 1989), undoubtedly due to the drying effects of the sun and the formation of inhospitable conditions for developing larvae.

Indoor Deposition

Indoor cases are particularly intriguing when estimating the post-mortem interval. Under these conditions, many considerations must be taken into account such as indoor versus outdoor temperature, proximity to a heating or cooling source, exposed versus shaded bodies, ability of insects and scavengers to access remains, and so forth. Given the frequent occurrence of death within the confines of a home, natural or otherwise, it would seem obvious that such studies need to be conducted in order to assess the rate of decomposition in comparison with alternative depositional contexts. When these considerations are coupled with the fact that the majority of individuals in the United States live in metropolitan areas, indoor studies in both urban and suburban areas appear crucial to a complete understanding of decomposition.

However, despite the clear and obvious need for indoor studies, only a few *outdoor* research projects have been conducted in urban and suburban areas in North America (Baumgartner 1988; Goff 1991; LeBlanc and Strongman 2002; Simpson and Strongman 2002). These types of studies are plagued by a number of issues, chief among them being the ability to conduct decompositional studies without stirring up the disgust of neighbors and the community, especially given the potential for the development of foul odors (Anderson 2011). As a result, little is known regarding decomposition rates and insect ecology both within and outside a home in these areas (2011). In fact, no carrion research had ever been conducted *inside* houses before 2011, primarily relying on anecdotal case histories for guidance regarding indoor decomposition (Goff 1991; Benecke 1998).

Therefore, considering the dire need for such studies, Anderson (2011) set out to compare decomposition rates and faunal colonization in indoor and outdoor settings in Edmonton, Alberta. In turn, the study found that indoor cases experienced a five day delay in colonization (2011). Compared to the outdoor deposition, indoor cases demonstrated many fewer insects and much lower numbers of larvae present (2011). Additionally, egg laying continued for most of the time, exhibiting extended colonization indoors (2011). Most importantly, decomposition was found to be slower in the indoor cases (2011). When these results are compared to studies in other areas of North America, important similarities and differences are observed.

Consistent with the regional variability described above, a different composition and diversity of species was observed in comparison to Hawaii (Goff 1991). However, both studies found much greater numbers of individual species outdoors versus indoors (Goff 1991; Anderson 2011). Interestingly, Goff (1991) reported findings suggesting some species of insects were restricted to remains discovered indoors, while others to those in outdoor contexts. This particular discovery is absolutely crucial to highlighting the critical need for comparative studies between depositional contexts, as they can bring to light factors which contribute to the differences in the rates of decay observed between indoor and outdoor environments. When multiple indoor studies can be compared across regions, even greater understandings regarding variables impacting decay will result. In total, these studies continue to support claims regarding the regional variability of insect activity and decomposition, as well as the differences in the rate of decay between both indoor and outdoor cases.

In order to build upon the limited existing knowledge regarding indoor decay patterns, studies should continue to incorporate indoor cases into their analyses. Retroactive studies can be particularly useful in this regard, especially given the issues mentioned above regarding odor, community sentiment, and so forth. Multivariate approaches to these types of studies can be extremely useful as well, not only modeling insect activity, but attempting to understand how additional factors, such as ambient temperature, shade, lack of rainfall, etc. work in unison to impact the rate of decomposition. Regardless, the findings described above point to the need for continued research in a variety of depositional contexts, so at to get at the critical differences influencing the rate of decay.

Buried Remains

For many decades now, the work conducted by Rodriguez and Bass (1985) at the University of Tennessee has guided the understanding of the interpretation of decomposition in cases of buried remains versus those left to decay on the surface. Therefore, when discussing the effects of burial type and depth, their seminal paper entitled, “Decomposition of Buried Bodies and Methods that May Aid in Their Location,” must be discussed. In this critical paper, Rodriguez and Bass (1985) outline the results of their study on the decomposition of buried remains, where it was observed that the rate of decay proceeds at a much slower pace in bodies buried two or more feet below the surface, compared to corpses left to decompose superficially. The most important factor accounting for the decompositional difference was found to be the decreased or absent carrion insect activity. In bodies buried at one foot below the surface, some evidence of blowflies, larvae, and beetles could be seen. On the surface layer above the corpses, blowflies were observed attempting to make their way to the bodies through small cracks in the soil, especially after a hard rain. However, those at depths below a foot did not show any insect activity. The resultant disruption in breeding activity, made most apparent in the blowfly community (which represents the most numerous carrion insect group) severely retarded the process of decay.

This conclusion is supported by the results of Simmons et al.’s (2010b) study, referenced above, which examined the role played by insect activity on the rate of decomposition in buried contexts. However, Simmons et al.’s (2010b) study takes on a new approach, incorporating the standardization of time and temperature as accumulated degree days. By making ADD the predictor variable in this scenario, the role played by insect activity is identified as the primary agent involved in determining the rate of decomposition in this scenario.

Additionally, it was seen that only those bodies buried a foot below the surface were accessible to scavengers, especially carnivores. As has been made clear, they also consume soft tissues and contribute to the disarticulation of remains. However, as pointed out by Haglund et al. (1988), one of the two major factors which affect which bones are recovered and the extent of damage is the "sheltering" of remains, i.e. buried, indoor contexts, etc. as opposed to surface depositions, with population density in the area being the other major contributing factor. At shallower depths, odors given off by the decomposing body are still easily detected by various insects and to a lesser degree by certain mammals (Rodriguez and Bass 1985). With the inability of insects or scavengers to access or detect more deeply buried bodies, breakdown of tissues progresses much slower, leaving only autolysis and bacterial putrefaction to degrade the corpse (Rodriguez 1997).

Before moving on, it should also be noted that additional studies have found insect access to be restricted in burial environments, sometimes showing fundamentally different insect species compared to the ground surface (VanLaerhoven and Anderson 1999; Campobasso et al. 2001). In regards to blow fly activity, VanLaerhoven and Anderson (1999) also report colonization to be absent in burials greater than 30 cm deep. Interestingly, carcasses buried immediately after death demonstrated no signs of colonization, whereas those buried two days after death displayed Calliphoridae larvae infestation two weeks after burial (1999). Lastly, Bachmann and Simmons (2010) report a highly significant difference in the rate of decomposition between carcasses exposed to insect activity for five hours after death, versus those where insect access was prevented. The insect access group showed an approximately 30% enhancement in decompositional advancement compared to the non-insect group (2010). These particular finds may not only have implications for the design of experimental research studies, but they also point out complications which can arise in regards to PMI estimation if bodies have been laying out before burial.

Moving on, the second most important factor producing differences in decompositional rates in buried remains was the insulating effects of the soil (Rodriguez and Bass 1985). Soil has the capability to create an efficient barrier to solar radiation, therefore decreasing both temperature and temperature fluctuations with soil depth (Rodriguez 1997). Thus, as temperature decreases with increasing depth, so does the rate of decomposition. For those remains buried more superficially, they are susceptible to temperatures similar to those above ground, as well as daily fluctuations (1997). Furthermore, the presence of ground water or clay soils which retain moisture can produce advanced adipocere formation, which slows decomposition by inhibiting the bacteria responsible for putrefaction (Rodriguez 1997; O’Brien and Kuehner 2007). Given the proximity of deeper burials to the water table, wet soil environments can commonly be found the further down one goes. Lastly, a body buried at shallow depths is susceptible to increased degradation by plants and soil-dwelling insects and bacteria (Rodriguez 1997). Plant roots grow towards a corpse, feeding off of its organic nutrients, eventually degrading clothing, skin, and skeletal remains (1997). Soil organisms are most prolific at shallow depths and therefore contribute to the rapid decay associated with burials in this enriched upper soil area (1997).

However, it is important to note that the environment to which the body has been exposed can alter expected assumptions at times, forcing researchers and investigators to analyze the full picture presented. In the case of shallow burials produced during winter months, corpses have been known to be associated with mummification (Rodriguez 1997). Due to the cold temperatures, decomposition is significantly slowed, but as temperatures shift with the onset of spring, a freeze-drying type of effect from desiccation of the tissues occurs, resulting in mummification (1997). This general process may be aided by snowfall or the freezing of the ground, making it considerably more difficult for insects and carnivores to penetrate the surface. Moreover, the availability of oxygen, producing either an aerobic or anaerobic environment, is critical to the progression of decomposition. In cases in which bodies are buried in wooden versus leaden shells, the oxygenated environments which result from disintegration of wood coffins, increases the rate of decomposition (Dent et al. 2004). Thus, despite the general pattern and rate of decomposition of buried cases versus those at shallower depths or deposited superficially on the surface, temperature and context must be taken into consideration in order to assess the post-mortem interval.

Aquatic Contexts

Contrary to the high volume of research conducted on buried and surface cases, the decomposition of corpses deposited in aquatic environments has been severely understudied. Some estimates suggest an 80-20% difference in studies between terrestrial and aquatic contexts (Merritt and Wallace 2010). Despite a recent up-tick in research, quantitative studies evaluating the post-mortem submersion interval are still lacking. This is a particularly important point given the fact that 77% of the earth's surface is covered in water, with over 140,000 individuals perishing in aquatic contexts each year (Yorulmaz et al. 2003). The result of such a dearth of research is a significant lack of understanding regarding the interrelationships between factors which impact the speed of decay in water and a failure to develop a quantitative estimation method which incorporates their joint effects. Additionally, such studies are needed to evaluate the widely-held belief that bodies deposited in aquatic contexts decay at a slower rate than those on the ground surface.

As expected, the reduced rate of decomposition is once again a result of cooler temperatures and reduced insect activity (Gill-King 1997; Rodriguez 1997). The cold temperatures assist in delaying the resurfacing of the body, which descends after the expulsion of air from the lungs (Rodriguez 1997; Nawrocki et al. 1997). Although the corpse is still susceptible to aquatic arthropods while submerged, blowflies will not be able to feed and reproduce on tissues until the body resurfaces, further slowing the rate of decay (Sorg et al. 1997). This particular observation is not helped by the fact that approximately eight of 13 orders of insects containing species which are minimally semi-aquatic are likely to be associated with corpses in aquatic habitats (Wallace et al. 2008). This is in stark contrast to the major groups of terrestrial insects known to colonize a body (Catts and Goff 1992).

Given the ability of bodies to initially be deposited in water, sink, and subsequently re-surface at a later date, significant limitations on accurate post-mortem submersion interval estimation using aquatic insects exists (Wallace et al. 2008). This particular point is exacerbated by the effects of tides, waves, and water temperature on the arthropod community. As demonstrated by Davis and Goff (2000), water is a key factor in the differences observed between intertidal and terrestrial contexts. As stated above, the mere presence of water limits the access of arthropods to the carcass. When this fact is coupled with the constant action of waves, tides, and currents, arthropod colonization becomes significantly hampered (2000).

Moreover, given the low temperatures characteristic of water throughout many months of the year, maggot mass activity becomes greatly retarded. With greater exposure to wave action and deeper water, oviposition decreases, lower levels of maggot mass activity develop, and internal carcass temperatures drop (Davis and Goff 2000). Considering the role played by insects on decay, by downplaying their involvement, only bacterial action remains as the primary method of breakdown. With lower internal temperatures however, the rate of bacterial activity subsides as well. Although scavenging activity can serve to hasten physical decomposition, it has been shown that the presence of clothing restricts the impact scavengers can have on the breakdown of tissues as well (Hobischak and Anderson 2002).

In total, the result was a much slower rate of biomass removal in the intertidal habitats, appearing to progress at rates two times as slow as the terrestrial contexts until the overwhelming majority of soft tissue was lost (Davis and Goff 2000). Given the sustained arthropod activity in the terrestrial contexts, coupled with a larger and more diverse community of insects observed (2000), it becomes apparent as to why bodies deposited in water decompose at slower rates. Therefore, as Merritt and Wallace (2001) point out, the determination of the post-mortem submersion interval is problematic for corpses found totally submerged in aquatic environments.

Given the dearth of objective aquatic studies, coupled with the need for improvements in the methods surrounding post-mortem submersion interval estimation methods, Hobischak and Anderson (2002) sought out to develop an insect successional database pertaining to pond and stream habitats for use in determining the PMSI in British Columbia. Their stated goal was to move away from the subjective nature of water death investigations and the unreliability of such estimates during use in legal testimony (2002). Therefore, albeit qualitatively, they also sought to better describe the decompositional changes which take place in aquatic environments, noting some differences compared to terrestrial contexts (2002). This particular study also built upon previous efforts by Hobischak and VanLaerhoven (1996) to begin a database regarding insect colonization, as well as qualify the decompositional and insect successional changes which occur through five stages.

In particular, Hobischak and Anderson (2002) found there to be a predictable sequence of invertebrate colonization, as well as habitat specific species, in regards to ponds and streams. However, they were unsure if the particular succession observed is carrion dependent or due to seasonal variation (2002). Additionally, they reported significantly lower numbers of insect species than in terrestrial habits in the same location (Dillon and Anderson 1996). This observation is in line with the results reported in Davis and Goff (2000).

Moreover, in comparison to a study conducted on decomposition on land in the same season and geographic location (Dillon and Anderson 1996), decomposition progressed nearly twice as slow in the aquatic habitats (Hobischak and Anderson 2002). This general trend is also in line with that described by Davis and Goff (2000). Hobischak and Anderson (2002) surmised that the slower rate of decomposition was intricately tied to the effect of water and temperature on aquatic insect activity. Specifically, they argued that if high moisture levels and low temperatures occurred simultaneously, larval development would not only be retarded, but an extremely high mortality rate for pre-pupal larvae would also occur (2002). In the end, when these particular factors are combined with the effects of tide, currents, and water depth, it becomes clearer as to why aquatic cases lag behind the rate of decomposition seen in terrestrial contexts. Given the ability of water to not only retard insect development, but wash away evidence of their appearance on carcasses, Hobischak and Anderson (2002) advise discretion in the use of evaluations of succession for determining the length of submergence. With this particular point in mind, it becomes even more critical to develop a set of quantitative methods incorporating the effects of multiple variables on decay in aquatic environments or risk falling prey to the pitfalls identified by Hobischak and Anderson.

Lastly, when the decompositional changes and insect succession were compared to freshwater cases in the area, similar early decay changes were observed (Hobischak and Anderson 2002). However, the descriptions from the coroner reports detailing information pertaining to the freshwater investigations lacked critical information and details, severely limiting comparisons (2002). In fact, only one case even mentioned the existence of invertebrates on the body, with four others discussing scavenging activity (2002).

Given the troubling descriptions observed in the coroner reports, Hobischak and Anderson (2002) offered important insights in regards to improving the medico-legal community's approach towards cases found in aquatic environments. In particular, they make it quite clear that the coroner's report was so vague in regards to the description of changes, invertebrates observed on the body, and indications of scavenging activity, that any comparisons between the research results and the cases were relatively useless, especially in regards to estimating PMSI in those cases (2002). Furthermore, they state that in order to avoid such issues in the future, better descriptions of the decompositional changes occurring in water must be developed, along with more specific categories of decomposition. This particular point is in line with arguments presented by Nawrocki (2011) and Megyesi et al. (2005), which call for additional, more specific stages of decomposition by which to evaluate decay, claiming the upside to be more accurate determinations of time since death. In regards to Hobischak and Anderson's (2002) conclusions, they argue for the use of better descriptors and categories so as to standardize description throughout the medico-legal and research community, fostering a greater ability to compare cases.

In turn, this call for improvements in description has been championed in subsequent quantitative studies, beginning with Megyesi et al. (2005). In regards to its use in aquatic contexts, Heaton et al. (2010) have utilized descriptions adapted from Megyesi et al. (2005), as well as Hobischak and Anderson (2002), applying them to rivers in the United Kingdom. Clearly, these crucial early studies have been embraced in the field of aquatic taphonomic study and applied to research aimed at utilizing accumulated degree days and multivariate regression analysis to estimate PMSI. In effect, Hobischak, Anderson, and VanLaerhoven's attempts to increase the objectivity of PMSI estimates have paved the way for more modern, quantitative approaches to decomposition in aquatic contexts. The result has been much clearer descriptions of the actual decompositional changes which occur, directly benefitting the medico-legal community.

Beyond insect activity, air and water temperature, it is hypothesized that many additional factors play varying roles in aquatic decomposition including pH, salinity, clothing, peri-mortem trauma, access to the water surface, water movement, biodiversity, floor composition, body weight, partial pressure of oxygen, and the chemical components of the environment (Gill-King 1997; Sorg et al. 1997; Ubelaker 1997; Anderson and Hobischak 2004). Given the number of factors at play, it becomes easier to understand how modeling aquatic decomposition can be quite difficult.

Likewise, research into decomposition on the deep sea Bathyal floor demonstrates considerable variation in the rate and mode of decomposition, appearing to be mainly influenced by the local faunal composition and elemental/chemical make-up of the aquatic environment (Dumser and Turkay 2008). Through this research, decompositional differences were discovered between deep sea, lacustrine, riverine, and coastal depositions. In the deep sea case, skeletonization and loss of cartilage was observed a remarkable three months after submersion (2008). This decay rate is in sharp contrast to a study of decomposition in German lakes and rivers (Reh 1969), as well as case examples from North America (Brooks and Brooks 1997), where despite submersion for several months, complete skeletonization was never observed. In regards to coastal contexts, in a series of cases from the Gulf of Maine, complete loss of soft tissue was observed 1 month after death, although cartilage was retained (Sorg et al. 1997). Cartilage loss was only seen as early as 10 months post-mortem, but could still be found in cases until 18 months after death (1997). These differences point to the crucial role played by the composition of local fauna and the accessibility of tissues.

Similarly, in a series of studies regarding the more specific decompositional changes which occur in a variety of aquatic environments, Anderson and Hobischak compared the breakdown of submerged pig carcasses in shallow marine, deep marine, standing freshwater, running freshwater, and terrestrial coastal contexts (Hobischak and Anderson 1999; Hobischak and Anderson 2002; Anderson and Hobischak 2004; Petrik et al. 2004). Much like what is seen in surface and indoor contexts, the studies showed aquatic decay changes to include bloating, shedding of hair, sloughing of skin, signs of lividity, and marbling, along with adipocere formation and the accumulation of algae, with bone staining. Specifically however, freshwater cases are said to exhibit stages of decomposition that are only slightly modified from the stages demonstrated in terrestrial environments (Hobischak and Anderson 1999; Hobischak and Anderson 2002; Anderson and Hobischak 2004). Marine depositions on the other hand, often demonstrate bloat, active, and advanced stages simultaneously, accumulating greater amounts of intestinal gas, leading to flotation (Anderson and Hobischak 2004). Regardless of marine or freshwater deposition, both show a longer bloat stage than terrestrial cases, as blowflies and other members of Calliphoridae fail to penetrate the carcass (2004). As can be clearly seen, not only does depositional context play a role in the rate of decay, but the particular type of aquatic environment does as well.

Additionally, the bacterial content and salinity of the water sources are crucial factors when comparing the rate of decay within various aquatic environments (Rodriguez 1997). As common sense suggests, bodies in swamps or polluted bodies of water will degrade much quicker than a corpse in a clean lake (1997). More importantly, decomposition in a salt water source is slower than in fresh water, due to the effect of salt on reducing bacterial action (1997). Given the proximity of coastal states, such as Delaware and New Jersey, to salt water oceans, as well as the high number of suicides involving jumps from bridges into brackish rivers and bays, knowledge of the effects of salt concentration and bacterial content can be crucial when studying decomposition and applying results in the field.

Adipocere

Perhaps equally as important is the effect of water, and moist environments in general, on the production of adipocere. Adipocere is produced through a process known as saponification or the hydrolysis of the body's fatty acids. The process usually occurs in anaerobic conditions in which fat is converted into saturated fatty acids by the presence of a variety of bacteria occurring in and on a decomposing body, such as *Clostridium perfringens* and *Clostridium frigidicanes* (Widya et al. 2012). The process also entails an increase in palmitic fatty acids and a decrease in oleic fatty acids, a trait characteristically found in adipocere (Den Dooren De Jong 1961; O'Brien and Kuehner 2007). In an adipocerous state, fat tissue expands becoming dense and thickened, causing the body to appear larger than its antemortem size, while water is extracted from the tissues for hydrolysis, giving the viscera a shrunken appearance (2007).

Importantly, due to the high melting point of hydroxy fatty acids, adipocere is stable, allowing the body to be preserved for an indefinite period of time (O' Brien and Kuehner 2007). This preservational affect is due to the need for large amounts of oxygen to decompose adipocere, thus preserving any corpse encased in it (Fiedler et al. 2009). These encasements are essentially waterproof, air tight, and insulating, protecting the body from fluctuations in temperature and water and microbial activity (Moses 2012). In fact, as long as fatty acids are present and conditions are acceptable, adipocere formation will persist (2012). This is best evidenced by reports of bodies as old as 7000 years with adipocere still being retained (Fiedler et al. 2009).

According to O'Brien's "Goldilocks Phenomenon," conditions must be "just right" for adipocere to form (O'Brien 1997). The basic requirements are a moist environment, warm temperatures, bacterial action, anaerobic conditions, and adipose tissue, with additional variables such as relative humidity and pressure playing a role as well (Mant and Furbank 1957; O'Brien and Kuehner 2007). The importance of these factors is made clear in Yan et al.'s (2001) study examining the effects played by water type on adipocere formation. The results showed that adipocere formed slower in chlorinated and saline water, compared to tap water, given the high concentrations of electrolytes in saline water and bacteria destroying chemicals in chlorinated water (2001). Together, the chemical composition of saline and chlorinated water inhibits bacterial activity and thus, adipocere formation (2001).

Continuing on, complete immersion does not appear to be necessary for adipocere development and consistent temperatures are not required, as long as they do not hold at extreme levels (O'Brien and Kuehner 2007). Actually, O'Brien and Kuehner (2007) argue that the optimum temperature range for formation appears to be from 21-45 degrees C. In conditions above and below the range, bacterial action and enzymatic release is depressed, preventing the formation of adipocere (2007). However, adipocere development has been known to develop in temperatures as cold as four and nine degrees Celsius (Sledzik and Micozzi 1997; O'Brien and Kuehner 2007). Clearly, many factors must be taken into consideration when attempting to understand the formation and production of adipocere.

However, despite the amount of research dedicated to adipocere and its preservational effects, estimations of time since death can still be seriously complicated by saponification. Even with the discovery of the "just right" conditions for adipocere development (O'Brien 1997), research regarding the timeline in which it develops is still very much in its infancy. Indeed, the current school of thought describes the process of adipocere formation to be highly variable, initiating development throughout various stages of decomposition and in a variety of environments (Anderson and Hobischak 2004; Forbes et al. 2004; Forbes et al. 2005; Fiedler et al. 2009; Pakosh and Rogers 2009; Moses 2012; Widya et al. 2012). In fact, despite the thought that waterlogged, anaerobic conditions are needed for adipocere formation, Forbes et al.'s (2005) illuminating study found that dry soils can also support adipocere, producing large masses of grayish white adipocere with no odor. Despite appearing to be contrary to the requirements of formation, the study concludes that it appears as if water within the tissues of a buried corpse is sufficient for adipocere. Therefore, bodies desiccating on the surface would be unable to hydrolyze fat. Additionally, Forbes et al. (2005) confirm that anaerobic conditions are the most favorable for development, as well as mildly alkaline soil. Given the multitude of processes involved in formation and the new insights provided, coupled with adipocere’s ability to develop in a wide-array of settings, it is still unknown under what exact circumstances adipocere will form (Widya et al. 2012; Ubelaker and Zarenko 2011).

As presently constituted, only early stage adipocere is correlated to accumulated degree days, observed to be more likely to occur after 630 ADDs (Widya et al. 2012). Given this accumulated degree day time frame, it appears as if adipocere is a feature of the more advanced stages of decomposition (2012). Additionally, during early decomposition, skin sloughing appears to promote adipocere formation, a result of the direct exposure of adipose tissue to water (2012). Nonetheless, the lack of specificity of these studies leaves much to be desired in the way of understanding adipocere development. Therefore, given the inherent variability described, the analysis of adipocere formation for the purposes of estimating the post-mortem interval is still far too misunderstood to be used with any degree of effectiveness. Going forward, given the fact that bodies deposited on surface layers, buried in pits, or dumped in aquatic environments can all be affected by water and thus saponified, further research is sorely needed to come to terms with the entire timetable regarding the formation of adipocere.

Trauma

As identified by Mann et al. (1990), traumatic sites were long-believed to be crucial factors influencing the rate of decay, tied in closely with the accessibility of insects and other organisms to the internal organs of remains.

Trauma, defined here as minimally resulting in penetrating wounds through the skin, was argued to facilitate access to the internal tissues of the body, thus speeding up the decay process (Mann et al. 1990). Given the fact that flies require moist areas on which to deposit eggs, these wounds were said to provide a favorable habitat for eggs to hatch while also maintaining air contact (Galloway et al. 1989; Haskell et al. 1997). Along the same vein, scavenging animals were said to gain easier access to the interior organs through these portal areas, with the result of these traumatic injuries being faster decay, compared to bodies without trauma (Mann et al. 1990).

However, first off, it should be noted that of first preference to insects are those openings on the face: the nose, mouth, and eyes (Haskell et al. 1997). Blowflies appear less attracted to post-mortem incisions than to natural body openings, especially in the context of competition for air which would eventually occur in those areas (Burger 1965). The nose and mouth emanate odors attractive to blowflies, while the eyes afford protection under the lids or within small spaces in the corners of the eye (Haskell et al. 1997). Additional areas of preference are folds in the hair and clothing, as well as the ground to body interface, as they all provide a source of protection from environmental factors, notably sun exposure (1997). Thus, although insects will colonize open spots on the body, they tend to prefer natural orifices.

Most damning are the results of multiple studies examining the differences in decay between traumatized and non-traumatized samples subjected to varying forms of peri-mortem injury. Cross and Simmons (2010) clearly demonstrate that trauma sites are not preferentially selected for oviposition in gunshot wound victims. Actually, as stated above, insects prefer the natural orifices of the body, which leads to no differences between trauma and non-trauma bodies in the time required to reach skeletonization. These results align with an investigation of exhumed bodies exhibiting injury, which too showed no acceleration of decomposition (Breitmeier et al. 2005). Lastly, research conducted on the effect of knife wounds on decay rates in pigs demonstrated no preferential oviposition in trauma areas and no effects on decomposition (Kelly et al. 2009). Thus, the claimed ability of peri-mortem trauma to increase the rate of decay has been turned on its head.

Despite this, critical information can sometimes be gleaned from areas of trauma, albeit not related to decomposition. If masses of maggots are observed to be clustered in one particular area devoid of a natural orifice, this can point to the potential presence of a perimortem injury. This particular indicator is useful in the early to early-late stages of decomposition, as Cross and Simmons (2010) noted the appearance of an earlier more rapid rate of tissue loss in the trauma pigs up to 310 accumulated degree days. Although not indicative of a preferential site for oviposition, traumatic areas provide larvae with quicker access to underlying soft tissue. However, the tissue loss eventually plateaus, reaching the same level of loss as that seen in non-traumatized pigs beyond 310 ADDs (2010). Also, given the preference of blowflies for natural openings, wound areas may sometimes not be consumed, thus preserving indications of trauma on mummified skin (Galloway et al. 1989; MacAulay et al. 2009a; 2009b). Thus, although the long-assumed link between trauma and the acceleration of decay has been shot down, traumatic sites can still prove useful to medico-legal investigations.

Rainfall

Interestingly, based on Mann and colleague’s (1990) rating scale, rainfall does not have a considerably large effect on the rate of decay. Given the large role humidity can play in the deterioration process, one would expect rainfall to accelerate decomposition or at the very least, disturb it. According to Mann et al. (1990), rainfall does not even retard maggot activity. Most of the larvae are able to use the body cavities as shelter from the rain and continue feeding on the corpse. Not even hard pelting rain has been seen to speed up destruction of the body tissues, as no connection has been observed between it and the sloughing of decomposed skin (1990). However, they do point out that during moderate to heavy rainfall, fly activity and thus egg-laying can be reduced or stopped altogether (1990). This can push time since death estimates back, allowing only minimum PMI determinations to be made so as to accommodate the effects of unknown confounding variables.

Ubelaker (1997) provides additional information regarding the effects of nonbiological agents such as climatic forces, arguing that groundwater can leach through the body, mineralizing hard tissues such as bone. This mineralization process can mask the typical appearance of "old" bone, giving it the feel, in terms of both weight and greasy texture, of "fresh" remains. In addition, rainfall can assist in the disarticulation process. If remains are deposited on a hillside, or swept up in a flash flood, the resulting spread of remains can mimic the effects of scavengers, potentially altering determinations of time since death.

Although rainfall is not described as a critical factor in and of itself, as with most variables implicated in the decomposition process, it has the potential to impact the roles played by other, more important factors such as aridity, humidity, insect activity, adipocere formation, disarticulation, bone mineralization, and so forth. Given its tight relationship with aridity and relative humidity, precipitation, in the form of rainfall, snow melts, and so forth, is an important variable to capture, especially if reliable sources regarding daily humidity rates are not available for the particular area under study (as was the case with Delaware).

Plant Activity

Although not specifically mentioned by Mann et al. (1990), plant activity and the presence of specific botanical remains may be of some value to forensic investigations. As described by Rodriguez and Bass (1985), and again by Rodriguez (1997) himself, plant activity can be of use regarding analyses of decomposing corpses, as well as in the detection of buried remains. Specifically, plant roots grow towards a corpse, feeding off of its organic nutrients, eventually degrading clothing, skin, and skeletal remains (Rodriguez 1997). Given enough time, plants roots, leaves, and branches can grow in, on, around, and through remains, often becoming intertwined with a corpse, leaving superficial indentations on bones and growing through the orbital sockets and other foramen of the body. If plant growth is substantial enough, it may even produce disarticulation of skeletal elements, masking the results of carnivorous activity and other taphonomic agents. However, these results can be interpreted to signal a prolonged post-mortem interval, given the time required to skeletonize a corpse and subsequently grow in and around the skeleton. These are all considerations which must be taken into account by investigators, making sure to observe plant growth and its markings on bone remains.

Most importantly for estimating time since death, forensic botany can aid in producing a minimum PMI determination. Based on analysis of growth rings on plant stems and roots, the minimum number of years required to reach that level of growth can be calculated (Hall 1997). In one particular case example, the growth rate of bryophytes and plant roots were analyzed to provide an accurate minimum PMI of an unidentified male in an advanced state of skeletonization in a wooded area in Northern Portugal (Cardoso et al. 2010). In addition, given the fact that nutrients leach into the soil from decomposing remains resulting in enhanced plant growth, nearby plants can be compared to those found at the scene, so as to compare increases in root and stem thickness in the plants fed by the corpse, to determine a minimum time since death (Hall 1997). Furthermore, based on the amount of growth into and under remains, the season of death can be approximated (Hall 1997).

Interestingly, the use of forensic botany is not just applicable to surface depositions. Semi-quantitative approaches to estimating the post-mortem submersion interval utilizing algae have also been developed as of late. Casamatta and Verb (2000) examined algal succession patterns in woodland streams on submerged carcasses to estimate the PMSI. Later, Haefner et al. (2004) demonstrated that the production of chlorophyll “a” in algae could be quantified and used for similar purposes. Lastly, Zimmerman and Wallace (2008) analyzed the algal/diatom diversity on a series of submerged carcasses and ceramic tiles in Delaware, discovering a significant relationship and strong correlation between progression of decomposition in pigs and decreases in the number of diatom species observed.

However, there are slight drawbacks to forensic botanical analysis. Given the fact that growth rings are produced in specific intervals, some of which are laid down every year, only a minimum PMI can be given (Hall 1997). For example, if a plant produces growth rings every year and two are observed, this indicates a minimum of two years since its development, given the fact that the rings do not provide information regarding how close or how far to its third year of growth the plant is. In the Northern Portugal case study described above, only a minimum PMI of three years could be provided based on the growth of plant roots (Cardoso et al. 2010). Several additional years needed to be added to account for the complete decomposition of the remains and the accurate identification of the six years which had elapsed since the individual's death. Also, it is difficult to know when the plant began its growth process in relation to the deposition of the body at the site. If the body was moved and then placed at the location of recovery, the plant may possibly have been growing prior to this event. Thus, when subsequent analyses of its age are given, if the point in time where the body accelerated plant growth cannot be determined, estimations of PMI may be off. All such interpretations and subsequent pitfalls are exacerbated by a lack of training and knowledge regarding botany.

As it applies to estimates of the post-mortem submersion interval, the use of algal diversity also contains its own pitfalls. To begin, diatoms are the initial colonizers in aquatic environments, meaning their presence and diversity is likely to taper off after about the three week mark (Zimmerman and Wallace 2008). In turn, their applicability appears limited in scope. Most importantly however, multiple factors exist in aquatic environments which complicate analyses utilizing underwater plant and insect remains. As demonstrated in multiple studies, temperature and current are two of the main factors that affect the rate of decomposition (Casamatta and Verb 2000; Haefner et al. 2004; Zimmerman and Wallace 2008). However, the ability to track their influence on a corpse over the course of the PMSI is extremely difficult and wrought with complications.

Additionally, as stated by Zimmerman and Wallace (2008), it is difficult to distinguish between ecological and geographical barriers regarding the overlap in the distribution of algae as multiple chemical (salinity, pH, elemental content) and physical (light, temperature, turbulence of water) factors exist. These factors make it difficult to develop a precise understanding of the expected algal/diatom diversity in a particular area, especially given seasonal fluctuations. Therefore, the use of algal diversity for estimating the PMSI should perhaps be used as more of a guide to direct investigations, as opposed to a concrete predictor.

Forensic botanical analysis clearly requires a specific knowledge of plant remains which many forensic investigators and Medical Examiners lack. Much like forensic entomology, an analysis of this type will require consultation with a specialist so as to determine growth and development, as well as the type of species collected. Given the nature of the discipline, if an examination of botanical remnants is required, an expert will need to be consulted. However, a general awareness of the flora of the area by investigators can only aid efforts to properly retrieve all relevant information from a scene.

Embalming

As common sense dictates, the use of preservative chemicals during the process of embalming can greatly affect the decay rate of a body, slowing decomposition to a halt. However, it was not included among the most influential factors by Mann et al. (1990) because of the rarity of encountering a body of forensic significance that has been previously embalmed.

Compared to the normal processes of deterioration of a corpse which begin by first demonstrating signs in the face (purging of fluids, swelling of the tongue, bulging of the eyes, discoloration, skin sloughing, marbling, etc.), embalmed bodies show decay in the buttocks and legs (Mann et al. 1990). Besides this observation, the tell-tale signs of embalming include an embalming scar where fluids were injected, a trocar button in the abdominal area, a metal wire for fastening the mouth closed, and plastic eye caps (1990).

An additional indicator of embalming or at least the chemical treatment of remains can be detected by noting the activity of insects. They will avoid certain chemicals, such as formalin, sometimes leaving the affected area untouched for months (Mann et al. 1990). If this is observed to be the case, especially around the natural orifices of the body or at sites of trauma or damage, investigators should look into prior potential chemical treatments.

Clothing and Body Wrapping

Clothing and body wrappings are particularly interesting variables that can complicate scenes and estimations of time since death. Although Mann et al. (1990) did not identify them as having a substantial bearing on decay, additional research studies have since indicated results to the contrary.

Early on, research regarding the relationship between insect activity and the presence of clothing appeared to suggest that clothing influences the rate of deterioration by providing insects with favorable habitats within which to consume tissues. After depositing eggs at the natural orifices of the body, once large numbers of flies colonized remains and thus overcrowded preferential areas, they would begin using folds in the clothing to lay their eggs (Haskell et al. 1997). Clothing could protect the body from sunlight, thus serving as a favorable habitat for maggots to take shelter from direct solar radiation (Mann et al. 1990). In theory, with a location to work comfortably, the maggots could process the tissues and thus speed up the rate of decay.

However, the results of these studies have been critiqued and turned on their head. As noted by Komar et al. (1998) in a review of decay cases in Alberta, Canada, clothing did not accelerate the decay process by protecting insects from sunlight, but rather appeared to protect underlying tissues from animals, wind, rain and sunlight. Likewise, in a study of clothed, wrapped, unclothed, and unwrapped bodies, although clothed and wrapped bodies had larger maggot masses, all of the wrapped carcasses took longer to dry out (Kelly et al. 2009). The unwrapped bodies were shown to lose mass quicker, resulting in a faster progression to the post-active decay phase or skeletonization (2009). In explanation, the authors hypothesized that the wrapped bodies allowed little evaporation, thereby keeping the body moist (2009). As a result, in conjunction with high heat, not only did the wrapped carcasses remain in the advanced decay stage for a longer period of time, but they also were the only samples to show maggot death (2009). In total, the wrapped bodies showed a preservation of moist tissue due to the lack of air circulation about the skin.

Interestingly, a study analyzing the effects of body coverings on preservation through an examination of adipocere development also supports such claims. As demonstrated by Notter and Stuart (2012), natural fibers, especially wool carpet and cotton clothing, followed by wool clothing, lead to an acceleration of adipocere development. However, even materials produced by synthetic fibers allow the formation process of adipocere to develop sooner than in unclothed bodies (2012). The main takeaways from the study point to the importance of the absorbency ability of natural fibers compared to synthetic materials, removing decomposition products, retaining moisture, allowing the formation of adipocere, and disrupting the decomposition process

(2012). Perhaps just as importantly however, the results also demonstrate that regardless of material type, clothing, wrappings, and coverings function to preserve remains more so than unclothed bodies.

Along the same vein, these results are in line with a study examining the impact of clothing on soft tissue preservation in the form of mummification. Given the ability of clothing to remove and absorb moisture from the skin's surface, the study concludes that this is the single most important determinant of post-mortem soft tissue mummification in both mortuary and forensic contexts (Aturaliya and Lukasewycz 1999). These results were seen to apply not only to surface exposed cases, but also in interred animal bodies (1999). Given the permeability of the skin, making it susceptible to moisture transfer, it also appears as if the skin is the last of a mummified body's tissues to desiccate (1999). Therefore, it appears as if clothing supports the preservation of remains, requiring the right conditions to develop into mummified or saponified bodies.

As additional support of these finds, Haglund and Sorg (2002) report findings suggesting that bodies tightly wrapped in plastic or synthetic fibers are associated with high levels of tissue preservation. Along the same vein, Gill-King (1997) found enclosed environments, whether natural or man-made, to slow decomposition as a result of the retardation of oxidative pressures. Lastly, Pakosh and Rogers (2009) also found that non-enclosed samples submerged in water lost soft tissue to a significantly greater extent than samples enclosed in plastic bags. Citing Rodriguez and Bass (1986), they state that the non-enclosed samples experienced continual bacterial action, while the enclosed samples experienced increasingly suppressed bacterial action due to decompositional by-product accumulation and reduced oxygen levels (Pakosh and Rogers 2009). Thus, given all of the evidence stated above, it becomes clear that forensic investigators must be sure to not only be aware of the potential effect of the depositional environment on decay, but also the ability of clothing, fibers, wrappings, enclosures and so forth, to slow decomposition.

Moreover, the relation of clothing to scavenging can also be of potential importance to reconstructing a scene and providing analysis of time since death. Given the fact that standards have been developed regarding the extent of scavenging activity on remains and its relation to the post-mortem interval, the protection offered by heavy clothing may serve as a considerable barrier to scavengers, thus presenting atypical scavenging effects for the amount of time the body has been exposed (Haglund 1997). Although additional studies are required to specify the effects of various types and amounts of clothing on scavenger activity, these types of considerations should be factored into analyses of time since death.

Lastly, two very interesting studies performed by Morse et al. (1983) and Rowe (1997), sought to research the time required for clothing, various textile fibers, and paper money to "biodegrade" either scattered across the ground or buried in the soil. Much like the results provided by Mann et al. (1990) for biological remains, they are able to show temperature to have the greatest effect, as it can provide an optimal working temperature for bacteria to deteriorate materials (Morse et al. 1983; Rowe 1997). Moisture, access to sunlight, and soil type also produced effects on degradation (Morse et al. 1983; Rowe 1997). Even materials that are protected by simply being within a shirt pocket were seen to deteriorate slower (Morse et al. 1983). If nothing else, the results provide another mechanism by which to determine PMI, if such materials are found in association with victims. However, it is important to keep in mind that time of year and temperature are huge factors here, as they guide the amount and type of clothing worn.

Body Size and Weight

This variable should logically appear to be a very important factor in the rate of decomposition. It would seem as if common sense would suggest that taller, more obese individuals would take longer to breakdown given the larger percentage of body fats or muscle. However, based on studies conducted at the Anthropology Research Facility in Tennessee, differences in body size and weight did not show any significant dissimilarity in the pace of decay (Mann et al. 1990). According to Mann et al. (1990), this lack of difference was due to the rapid loss of body mass in obese individuals, with a liquefaction of body fats. When all variables were held equal, not only was there no difference in the speed of deterioration between people of varying weights, but no difference was seen between the sexes either (1990).

However, subsequent studies have contradicted such claims. For example, in a study by Hewadikaram and Goff (1991), two pig carcasses weighing 8.4 and 15.1 kilograms, respectively, showed greater thermal mass rises and a faster decomposition rate in the heavier body. Although no differences were observed in regards to the composition and pattern of succession of associated fauna, the heavier carcass showed a faster loss of biomass.

Conversely, Simmons et al. (2010a) compared the effect of carcass size using two distinct groups. One group was composed of carcasses of varying size exposed to insect activity, while the other group was derived from indoor, buried, or submerged cases where insect access was prevented (2010a). For size classes in the group where insect activity was excluded, no difference was found in the rate of decomposition (2010a); supporting the assertions made by Mann et al. (1990). However, in the cases where insects were granted access, body size was a significant factor, with smaller carcasses decomposing faster (Simmons et al. 2010a). They postulate that the slower rate of decomposition in larger carcasses may be due to the greater amount of tissue for the insects to consume (2010a). Thus, with a greater body mass present for insects to feed on, time to skeletonization is prolonged (2010a).

However, a major caveat to their conclusion is that given the lack of difference when insect activity was precluded, it is not body size itself which is an important factor in altering the rate of decay. Rather, the presence or absence of insect activity is the driving force in that regard. Therefore, when viewed from that perspective, it appears as if both Mann et al. (1990), as well as the subsequent studies challenging those results, are both correct in different ways.

In regards to the differences in the rate of decay between the sexes, Zhou and Byard (2011) point out the fact that obesity can accelerate decomposition, as subcutaneous and abdominal fat have insulating properties that slow the rate of cooling. If a body takes longer to cool, bacterial growth can continue to flourish. As for its relation to the sexes, they point out that males cool more rapidly than females of identical weight, due to the higher fat content in females (2011). Therefore, based on the unequal cooling rate, differences in the onset of early decompositional changes may result.

Surface Placed On

Although considerable differences in the rate of decay exist between bodies deposited in different types of burials, as well as between exposed versus shaded carcasses, the dissimilarities noted regarding decomposition of remains placed on concrete compared to directly on the ground appear not to be as noteworthy (Mann et al. 1990). Although bodies lying on concrete are usually seen to decay slower and mummify faster, this is not always the case. Mann et al. (1990) caution that until a provable explanation accounting for the results seen can be developed, the "common sense" judgment that decay occurs faster on the ground due to exposure to the natural environment, may not be capturing the full essence of the factors at play. If one gleans no other information from this chapter or the results of this study, it should be that the variables involved in the decomposition process are so interrelated and dependent upon one another, that it may be impossible to parcel them apart. Therefore, it may very well be the case that many of the long-held assumptions regarding the effects of these variables fail to capture the full picture of the process of decomposition.

Body Position

Depending on the circumstances of the scene and the characteristics of the environment into which a corpse has been deposited, multiple body positions are possible. Obviously the two commonly thought of positions are supine and prone, but if an individual is on the couch or in the car, seated bodies made be found as well. Moreover, individuals are oftentimes found in bed, turned onto their left or right sides. Additionally, a commonly encountered theme in wooded environments is cases involving hangings, whether completely suspended off the ground or with the feet in contact with the surface. Given the multiple positions possible, it is only natural to attempt to analyze whether decomposition progresses differently between them.

Prone and supine bodies are the most experimentally studied positions. These are the "normal" positions associated with death, leading to the pooling of blood via gravitational pull during livor mortis. As one would expect, studies such as Aturaliya and Lukasewycz (1999) have found enhanced body water loss in bodies positioned horizontally versus vertically. They surmise that these differences are due to the wider spread of bacteria and enzyme laden abdominal fluid about the dependent areas, resulting from increased diaphragm and tissue digestion and liquefaction of the organs' tissue structure (1999). Clearly, based on these results, it appears warranted to conclude that supine and prone bodies, as well as those found lying on their sides, are likely quicker to decompose than seated and vertically-positioned bodies, secondary to retention of the diaphragm's integrity in non-horizontally placed corpses.

In regards to studies conducted on positions beyond horizontally-placed corpses, the trend in research is beginning to move away from the reliance on case examples towards experimental research. For example, Shalaby et al. (2000) compared the patterns of decomposition between pig carcasses completely suspended off the ground and those hanging but in contact with the ground. The study found that the rate of biomass removal from the fully suspended carcass was significantly slower than that of the control carcass (2000). These results are likely due to the reduction in the number and diversity of the arthropod species colonizing the hanging body; therefore, preventing higher maggot mass temperatures (2000). Interestingly, although there were fewer insects on the fully suspended carcass, significant arthropod activity was observed directly underneath the body in the "drip zone." Their particular location points to the fact that the insects either fed on the remnants falling from the body or that they fell off of the body themselves after initial colonization, thereby being restricted to the substrate. As a result, a smaller arthropod community develops on the carcass. These particular results, patterns, and locations of insect activity are fully supported by previous research conducted by Early and Goff (1986) and Goff (1992). Lastly, the hanging carcass was exposed to the cooling effects of the air, with internal temperatures more closely approximating ambient temperature, resulting in a delayed progression through the stages of decomposition (Shalaby et al. 2000). The control carcass was less subject to cooling and therefore was unable to stave off the physical changes of decay. Therefore, these results suggest a correlation between temperature, especially that derived from maggot masses, and body position, reflective of the slower decomposition observed in fully hanging carcasses.

Overall, it appears as if supine and prone bodies are the quickest to decompose. Following that are bodies found lying on their sides. In regards to vertically-positioned bodies, given the mix of vertical and horizontal placement of body parts, seated cases would logically be next in the sequence. Lastly, vertically-positioned bodies appear to be the slowest to decompose, especially those found in a fully suspended state as a result of hanging.

Soil Type and pH

In their discussion of variables affecting the rate of decay, Mann and colleagues (1990) state that studies are being undertaken to test the effect of soil pH on the rate of decomposition. Fortunately, the effects of soil pH on decay are now relatively well known. In a recent study conducted by Deborah Surabian (2011), a soil scientist from the Natural Resources Conservation Service, a guide was developed for understanding the breakdown of a cadaver and the preservation of bone in soil.

Although many factors involved in the decomposition of remains have been discussed, some believe that soil chemistry is one of the most influential extrinsic factors involved in the deterioration of bone, once soft tissue has been lost (Gordon and Buikstra 1981; Haslam and Tibbett 2009). Based on the results of her study, Surabian (2011) confirms the importance of soil acidity to the deterioration of osseous material as significant correlations between the two were found. Preservation was favored in soils above a pH level of 5.3, but disadvantageous at levels below that mark (Surabian 2011). A study conducted by Nielsen-Marsh et al. (2007) confirms that trend, showing an increase in bone destruction and absence from sites the more acidic the soil becomes, especially under pH levels of 5.5. The result of this reaction has to do in part with highly acidic soil's ability to rapidly deteriorate bone (relatively speaking) by altering its inorganic hydroxylapatite, which makes up the majority of bone's material (Nafte 2000). As shown in a case study described by Ubelaker (1997), neutral soils do not show such destruction. Interestingly though, although acidic soils appear to be dominated by fungal communities, alkaline soils may also show a dominance of fungi, especially considering the effect on soil conditions resulting from the decomposition of a cadaver (Carter et al. 2007). On the other hand, neutral soils provide conditions where bacteria display a competitive advantage (2007).

Along the same vein, a study by Haslam and Tibbett (2009) demonstrated results in line with those described above. When comparing the decomposition of skeletal muscle tissue in acidic, neutral, and alkaline soils, it was found that soil type had a considerable effect on the decomposition of the tissue (2009). In fact, not only were differences observed between the soil types, but the acidic soil demonstrated a rate of decomposition up to three times as fast as that observed in the alkaline soil (2009). Additionally, it appears as if the rate of microbial respiration is correlated to the rate of soft tissue loss, highlighting the importance of the microbial community to decomposition (2009). Also, much like the earlier studies mentioned above, an increase in the alkalinity of the immediate soil environment was noticed at first, due to the leaching of decompositional by-products, before eventually becoming more acidic and reaching pH values similar to that measured at the outset (2009). In total, the authors suggest greater consideration of soil type in taphonomic analyses (2009). However, it should be kept in mind that they used skeletal muscle tissues, as opposed to full corpses, to conduct their analysis. Nonetheless, given the similarities between studies, it clearly demonstrates the need to take soil environment into account when assessing not only soft tissue, but also skeletal tissue deterioration.

Furthermore, soils high in clay content, which have an increased ability to hold moisture, inhibit the breakdown of corpses by producing a reducing atmosphere insufficient to support efficient microbial decomposers (Manhein 1997; Carter et al. 2008). On a related note, Surabian (2011) also indicates that mildly alkaline soil produces favorable conditions for the formation of adipocere, especially in the context of moist soil textures and reducing conditions. A specific discussion of adipocere, and its relationship to decay, can be found elsewhere in this paper. On the other hand, although soils high in the content of sand have low moisture content, they promote the drainage of water and thus desiccation, also providing a favorable habitat for preservation (Micozzi 1991).

However, contrary to these results, when it comes to skeletonization, some researchers suggest the opposite relationship between moisture and decomposition exists. Although the correlation between moist soil and the preservation of remains may hold true (Manhein 1997; Carter et al. 2007), Jaggers and Rogers (2009) suggest that bones in higher moisture environments exhibit a greater net weight loss than those in drier soils. In particular, three main conclusions are drawn: 1.) buried bones lose mass over time, regardless of moisture, 2.) bones in higher moisture soil environments lose more weight over 150 days than those in drier soils, and 3.) bones in high moisture soil environments do not absorb more water over 150 days than those in drier soils (2009). In addition, in regards to macroscopic bone changes, color, texture, and condition of bone remains do not appear to change over 150 days regardless of soil environment (2009). Although these macroscopic events were not observed, it has been shown that collagen is eliminated by bacterial collagenases, while the loss of mineral hydroxyapatite proceeds by inorganic mineral weathering (Dent et al. 2004). Thus, based on the results of this analysis, although moisture may serve to preserve tissues under the right conditions, high moisture soils appear to accelerate the breakdown of skeletal elements.

Furthermore, as summarized by Dent et al. (2004), much like the decomposition of soft tissue in soil, acidic soils are the most destructive to bone material, dissolving the organic matrix of hydroxyapatite (Goffer 1980; Henderson 1987). Under aerobic, non-acidic conditions, bone tends to remain in good condition, but may demonstrate surface coarsening and cracking in fine sands (Goffer 1980; Henderson 1987). Nonetheless, dry sand assists preservation due to reduced bacterial action (Janaway 1997). In calcareous sand, loam, or sandy-loam, the presence of damp conditions and more oxygen may lead to a rougher bone surface, cracking, and warping (Goffer 1980; Henderson 1987). Bone found in calcareous gravels will lose collagen, resembling chalk (Goffer 1980; Henderson 1987). Overall, bone preserves best in dry soil with neutral or slightly alkaline pH (Janaway 1997), aligning with those studies examining soft tissue decomposition in soil (Nielsen-Marsh et al. 2007; Haslam and Tibbett 2009). Clearly, these particular soil environments are of importance to note and factor into estimations of time since death under burial conditions. Having said that, it has yet to be determined if these factors are quite as important in regards to bodies left to decompose on the ground surface.

It should be remembered that buried bodies below depths of two or more feet tend to decompose at a slower rate than on surface layers or at shallow depths (Rodriguez and Bass 1985). In fact, Rodriguez and Bass (1985) show a significant increase in alkalinity in these cases, between 0.5 to 2.1 pH levels, based on values gathered before and after exhumation of each cadaver (1985). This alkalinity, in conjunction with lower soil and cadaver temperatures, as well as increases in moisture at deeper depths, may account in part for the differences in the rate of decay seen between buried bodies and those deposited on surface layers. These results are in line with those reported later by Haslam and Tibbett (2009).

Soil tests also have additional uses to forensic investigators. As described by Rodriguez and Bass (1985), by detecting changes in soil pH and cadaver temperatures with pH probes or temperature loggers, investigators may have a new means by which to locate a buried body (1985). Moreover, Vass et al. (1992) claim that with a general description of a body’s weight, along with information about temperature, the post-mortem interval can be determined by measuring the ratio of volatile fatty acids in the soil below a decomposing body. Although this study has been critiqued as of late, it provides an interesting use of soil beyond measurements of pH levels.

Thus, it is obvious that if access to soil pH data at the recovery site is available, it can be of value to interpreting the rate of decay of a corpse. Unfortunately, in cases of actualistic, retrospective studies, these values are rarely recorded. Attempts to back-track and assess the soil pH in the general location in which a specific body was found can, at best, only provide a basic description of the soil type in the area, which corresponds to a less specific pH range compared to actual measurements at the time of recovery.

Summary of Variables Believed to Alter Decomposition

Based on decades worth of research regarding the effects of environmental and contextual variables on the process of decomposition, it is clear that various factors play critical roles in the rate of decay of human corpses. Although some variables such as temperature, insect activity, and depositional environment exert larger influences in some respects, all of the factors described above are inextricably linked and require attention in order to understand the bigger picture at play in regards to decay. This is especially true when providing estimates of post-mortem interval, as no one criterion accounts for the decompositional changes seen, instead necessitating an understanding of all variables in their specific environmental contexts.

Having stated the interrelationships demonstrated by these factors in a number of studies, the point must be made that applied research under actual forensic conditions must continue. Given the convenience of experimental studies, in which various variables can be controlled for and isolated, or where research designs can be configured in such a way as to evaluate only one or two variables of interest, it is clear why such experimental research is popular. However, if the current school of thought regarding the highly intertwined nature of these variables holds true, actualistic studies under real-life conditions are needed, so as to confirm this theory and more fully understand how the effects of the various factors at play either change, or stay the same, within various environmental contexts around the country. Additionally, actualistic studies can evaluate decomposition involving the presence of all variables involved in real-life forensic settings; therefore, gaining a better picture of decay as it actually occurs. In turn, the standards and equations upon which post-mortem interval estimates are based can be refined and stand a better chance at maintaining reliability, validity, and accuracy.

Ultimately, given the number of factors and intricate relationships among all of the variables presented, a study of this nature is sorely needed to centralize the effects of all such factors and account for their role in decomposition in a standardized, quantitative fashion. If not, the field will continue to be mired in qualitative descriptions, providing “best guesses” of the approximate roles played by all such variables, only continuing the tradition of wide, unsubstantiated time since death estimates.

Chapter Six: Climatic and Environmental Conditions in Delaware

In order to rationalize the development of region-specific standards and equations by which to estimate the post-mortem interval, the particular area in question must be demonstrated to be environmentally and climatically unique from all other areas where such studies have been undertaken in the past. Thus, in order to do so, a discussion of the particular climatic and environmental conditions to which Delaware is exposed is warranted.

Climate Classification Systems

Köppen-Geiger Classification System

Two main classification systems are employed throughout the world in order to identify the general climatic zones which exist. These systems usually correspond to vegetation distribution, with each climate type dominated by one vegetation zone or eco-region (Belda et al. 2014). The first among them was a quantitative classification system developed by Wladimir Köppen in 1900 (2014). Although various classification systems have since been developed, Köppen's original approach (Köppen 1923; 1931; 1936) and its modifications are still the basis for many of the systems still in use today (Belda et al. 2014). In fact, Kottek et al. (2006) recently released the first digital Köppen-Geiger world map, combining Köppen's (1936) methodological approach with that of Geiger (1954), in regards to observed climatic conditions in the last half of the 20th century. Subsequent to the release, Rubel and Kottek (2010) produced a series of digital world maps spanning the entire 20th century. Given the accessibility of these digitized maps in today's technological world, this particular approach to climate classification is now preferred.

Köppen-Trewartha Classification System

However, despite the convenience of the updated Köppen-Geiger system, many researchers do not agree with the climatic divisions represented by the classification system. In response, Trewartha (Trewartha 1968; Trewartha and Horn 1980) released a modified version of the Köppen-derived system, adjusting both the original temperature criteria and threshold separating wet and dry climates (Belda et al. 2014). Based on the new approach to climatic typing, the resulting system was deemed the Köppen-Trewartha Classification (2014). Following its release, the Köppen-Trewartha system has been utilized by a multitude of studies recognizing the fact that it is a better descriptor of vegetative zones in particular areas, compared to the Köppen-Geiger system. Specifically, these studies have employed the Köppen-Trewartha classification system to research concerning shifts in climate types relating to the Pacific and North Atlantic climate oscillations (Fraedrich et al. 2001), atmospheric circulation models of the last interglacial and glacial climates (Guetter and Kutzbach 1990), projected future climate areas in China (Baker et al. 2010), the impact of climate change on vegetation in the Arctic region (Feng et al. 2012), validation of regional climate models over Europe (de Castro et al. 2007), the effect of global warming on Europe (Gerstengarbe and Werner 2009), and many more. As can be seen, these studies are extremely recent, highlighting the applicability of the Trewartha modified system to today's climatic zones.

Köppen versus Trewartha

When compared to the Köppen-Geiger system, the Köppen-Trewartha Classification makes many significant modifications. In particular, although employing an approach similar to Köppen's (1936) in regards to the determination of climate types based on long-term annual and monthly averages of surface air temperature and precipitation, Trewartha (1968) introduces adjustments so that climate zones better correspond with observed boundaries of natural landscapes (de Castro et al. 2007; Belda et al. 2014). By doing so, Trewartha's data also clarifies several vague areas inherent to Köppen's original formulations (Belda et al. 2014). Specifically, the main modifications between Trewartha (1968) and Köppen (1936) deal directly with the definitions of climate zones C and D, a newly-defined E type, and different thresholds between wet and dry climates (Belda et al. 2014). For the purposes of this discussion, the differences between climate types C and D will be explored, as they are the zones applicable to Delaware and the Delaware River Valley.

To begin, the C group, as originally described by Köppen-Geiger, corresponds to a humid sub-tropical climate (Belda et al. 2014). Among the areas included in this climate type are the southeastern Atlantic states, ranging from Florida to Virginia. Also included in that group are the Gulf States ranging from Texas to Alabama, as well as Southern portions of Kansas, Missouri, Illinois, Indiana, and Ohio. As if this general grouping of the entire southcentral, midwestern, and southeastern parts of the United States into one single zone were not enough, the Köppen-Geiger system also includes the midatlantic states including Maryland, Washington D.C., New Jersey, southeastern Pennsylvania, Delaware, New York City, and Long Island (see Figure 1). This zone is supposedly characterized by long, hot, humid, and nearly tropical summers, with mild winters only occasionally reaching freezing temperatures (Belda et al. 2014).

As any citizen of these midatlantic states can attest to, the climate in this particular area is nothing like that experienced in Florida, Texas, Louisiana, Georgia, and so forth. Although the summers are indeed hot and humid, the winters are certainly not mild and often reach temperatures below the freezing point. Nonetheless, the Köppen-Geiger system lumps all of the aforementioned states into one general climate zone. To further emphasize the inadequacies inherent in this method of classification, it should also be pointed out that the Köppen-Geiger system groups Washington and Oregon into the same climate type as Southern California (see Figure 1). Given the clear misalignment of climate zones, researchers have called for changes to the C and D zones, citing the humid sub-tropical group to be far too broad (Griffith 1966).

Recognizing the inconsistencies inherent in this classification system, Trewartha developed new standards to address this inefficient grouping method, redefining the middle latitudes to more accurately reflect vegetative zoning and the actual climates in these areas. In turn, Trewartha developed a new representation of climate zones both globally and in the United States (see Figures 2 and 3), drawing up new definitions of climate types and sub-types (see Table 8) (Belda et al. 2014). In particular, contrary to the definitions presented by Köppen (1936) (see Table 7), Trewartha (1968; Trewartha and Horn 1980) reclassifies group C to include those areas with a mean temperature above 10 degrees C for eight or more months of the year (see Table 8). This newly defined C type corresponds with humid, sub-tropical climates beginning from North Carolina down to Florida and over to the middle of Texas. The upper border of this new climate zone runs along the Northern borders of North Carolina, Tennessee, Arkansas and Oklahoma. As a result, group D is now classified as a temperate climate, consisting of areas demonstrating a mean temperature above 10 degrees C for four to seven months of the year (see Table 8). More importantly, southeastern Pennsylvania, Delaware, and

New Jersey are now reclassified as temperate climates under the newly defined D climate type.

Having stated the obvious concerns regarding the Köppen-Geiger system, as well as the changes imposed by Trewartha, it is important to compare the two. Based on an analysis of both climate systems, Belda et al. (2014) report that the Trewartha system is more realistic in placing boundaries, provides more detailed depictions of climate types, is the least demanding on data (as it primarily based on precipitation and temperature), and has proven suitable for the creation of maps of global Ecological Zones for the Forest Resources Programme of the United Nations Food and Agriculture Organization (FAO). In fact, the FAO (2001) has come out as a chief supporter of the Trewartha system stating, "there is a demonstrated good correspondence between the Köppen-Trewartha subzones or climate types and the natural climax vegetation types and soils within them." Lastly, as stated by Akin (1991), the reclassification of climate types is viewed as a more realistic and real world representation of the global climate. Therefore, given the more realistic application of climate data in the Köppen-Trewartha Classification, coupled with the release of digital maps of the Köppen-Geiger system by Kottek et al. (2006) and Rubel and Kottek (2010), Belda et al. (2014) decided to create digital maps of the Köppen-Trewartha system utilizing up-to-date Climate Research Unit data. These maps are now accessible via the internet through this study, hopefully leading to a rediscovery of the utility of the Trewartha system for climate type classification.

Emphasizing the Need for Region-Specific Decomposition Studies

Thus, given how much better suited the Köppen-Trewartha Classification is for defining the temperate climate of southeastern Pennsylvania, New Jersey, and Delaware, coupled with the fact that no retroactive, actualistic, applied decomposition studies have ever been conducted in this particular climate type, this study is justified in its attempt to devise a PMI equation specific to the Delaware River Valley Region. Additionally, given the fact that traditional estimates of time since death in this area have been derived from experimental studies developed out of the University of Tennessee, this confirms that both regions are, in fact, in separate and distinct climatic zones, once again demonstrating the need for a regional study. Lastly, when these considerations are coupled with the call for research studies in a variety of environmental and climatic regions throughout the country (Mann et al. 1990; Haskell 1997; Megyesi et al. 2005; Jaggers and Rogers 2009; Parks 2011; Bygarski and LeBlanc 2013; Dabbs and Martin 2013), there is no doubt that a decomposition study in the Delaware River Valley Region is warranted.

Temperature

In order to further drive home the point regarding the need for region-specific decomposition studies based on the particular climatic conditions in the Delaware River Valley Region, a discussion regarding specific environmental variables in Delaware will be provided. Although decomposition studies such as Megyesi et al. (2005) incorporate data from a variety of regions, it is always important to understand the specific environmental and ecological contexts which exist in a researcher's particular area of study, especially when region-specific standards are to be derived. Lastly, given the fact that the University of Tennessee's Anthropology Research Facility is the closest location to the Delaware River Valley where decomposition studies have been undertaken on human corpses, it is important to compare environmental conditions between both locales.

Having stated that, according to a 2005 study conducted by the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC), Delaware's climate is temperate year round with the lowest average monthly temperatures ranging from 32.1-40 degrees F, with the highest average monthly temperatures ranging from 70.1-80 degrees F in Kent and Sussex Counties (see Figures 4 and 5). The County North of them, New Castle County, shows the same average monthly high temperatures, but its lowest average monthly temperatures range from 20-32 degrees F (see Figures 4 and 5; NOAA, NCDC 2005). The average temperature during the summer months ranges from 70.1-80 degrees F for all three Counties (NOAA, NCDC 2005).

In addition, Delaware's mean annual temperature differs between New Castle County and both Counties to the South, Kent and Sussex (NOAA, NCDC 2005). In New Castle County, the mean annual temperature ranges from 50.1-55 degrees F; an average slightly below the mean annual temperature range of 55.1-60 degrees F seen in the remaining two Counties (See Figure 6; NOAA, NCDC 2005). Given the rather small disparity between the Counties, not much difference should be observed in the decay patterns between Northern, Central and Southern Delaware.

Before moving on to the next variable, a word should be said regarding Delaware's temperature in comparison to eastern Tennessee, where the Anthropology Research Facility of the University of Tennessee at Knoxville stands. Many PMI studies have been conducted there, believed to have the same "humid sub-tropical" climate as Delaware based on the Köppen-Geiger classification system (Kottek et al. 2006). Despite the urging of researchers from the University of Tennessee-Knoxville regarding the need for additional studies in a variety of environmental and ecological settings, one may wonder if the standards developed at UT-Knoxville are applicable to Delaware's environment based on comparisons of temperature. Based off of the latest figures published in 2013 from the "Comparative Climate Data: For the United States Through 2012" study conducted jointly by the NOAA, National Environmental Satellite Data and Information Service (NESDIS), and the National Climatic Data Center (NCDC), Knoxville, Tennessee and Wilmington, Delaware differ in several climatic categories. Once again, these differences appear to support the distinctions made by the Köppen-Trewartha classification system.

In regards to specific differences regarding cold temperatures, the mean number of days with minimum temperatures of 32 degrees F or less comes in at 98 days for Wilmington, compared to only 72 days for Knoxville. In addition, the mean monthly temperatures differ considerably during the winter months, coming in at 40.8, 38.2, 42.4, and 50.3 degrees F in Knoxville for December, January, February, and March respectively. These figures are in comparison to temperatures in Wilmington of 36.7, 32.4, 35.1, and 43.0 degrees F over the same months. During January, Wilmington averages temperatures at the freezing point, while Knoxville hovers over five degrees higher. Additionally, the daily average minimum temperature in Wilmington is several degrees below the freezing point in December, January, and February, while only January demonstrates temperatures well below freezing in Knoxville. Likewise, the average snowfall amount per year in Delaware is 22.1 inches, while Knoxville only experiences 11.6 inches of snow annually. Given the optimal temperature range at which bacteria operate, these temperature differences may have substantial effects on the preservation of soft tissue, resulting in decompositional differences between both locations. If bacterial growth is greatly retarded or halted altogether for longer periods of time in Delaware, estimations of PMI will need to be done with standards specific to the area.

Furthermore, as mentioned above, flies will not lay eggs at temperatures below the freezing point, as the cold will kill both the eggs and maggot larvae (Mann et al. 1990). If insects are not ovipositing close to 30 days less in Knoxville compared to Wilmington, this can have a critical effect on the rate of decay of human remains and the determination of time since death, not to mention the general effects of colder environments and snow on decomposition, including mummification, freezing, thawing, etc. As a matter of fact, in a series of studies conducted by Micozzi (1986; 1997), animal corpses which were frozen and then thawed disarticulated at a faster rate than fresh killed animals, due to the disruption of tissues as a result of freezing. If such effects apply to the decay of human corpses during winter months, the added exposure to colder temperatures in Delaware may significantly alter the time required to reach specific decompositional stages, especially in comparison to the University of Tennessee studies.

Lastly, the study reveals that Knoxville sees an average of 28 days per year in excess of 90 degrees F or higher, compared to just 19 in Wilmington. Given the effects of increased temperature of insect activity and the desiccation of tissues, the temperature disparities may very well produce differences in the time needed to reach specific decompositional stages in both regions.

Determinations of the post-mortem interval are already plagued by an inverse relationship between the accuracy of PMI estimation and the longer an individual has been deceased. If standards inappropriate to the specific environmental and ecological contexts of the area are being used, inaccuracies are sure to increase. Seeing as to how correct PMI determinations are critical to forensic investigations of unknown remains, potentially including or excluding possible missing person matches, identifying suspects, and closing cases, it is crucial that specific standards be developed in each particular environmental context.

Humidity/Aridity

Based off of figures gathered from the “Comparative Climate Data: For the United States Through 2012” study conducted jointly by the NOAA, NESDIS, and NCDC in 2013, Knoxville, Tennessee and Wilmington, Delaware are once again seen to differ, this time in regards to average relative humidity. The relative humidity was expressed as a percentage of the measure of the amount of moisture in the air compared to the maximum amount of moisture the air can hold at the same temperature and pressure. Values were given for both morning and afternoon observations, with the knowledge that maximum relative humidity is usually reached during morning hours. When the relative humidity percentages were compared, the results demonstrated that Wilmington had lower overall averages, with a yearly mean of 78 percent humidity in the morning and 55 percent humidity in the afternoon. This is compared to an annual mean of 85 percent humidity in the morning and 58 percent humidity in the afternoon in Knoxville, Tennessee. What’s more, Wilmington showed lower average humidity for both mornings and afternoons every single month compared to Knoxville.

Most importantly for decay rates, both locations differed by a minimum of 5 percent average humidity during the summer months of June, July, and August, as well as the last full spring month, May. Given the fact that increases in humidity are critical to the deceleration of the drying out of tissues, allowing for increased access and activity by insects, as well as bacteria, a difference of 5 percentage points across multiple months may prove to be an important factor. This data also supports the new climatic zone definitions proposed by Trewartha (Trewartha 1968; Trewartha and Horn 1980). Lastly, as Ross and Cunningham (2011) state best, these differences between sites highlight the need to better understand micro-environments and the effect they have on the decomposition process.

Precipitation

According to a study conducted by the U.S. Department of the Interior and the U.S. Geological Survey, from the period of 1961-1990, Delaware averaged an annual precipitation total of 43.62 inches (see Figure 7). According to the NOAA, NESDIS, NCDC (2013) study, Wilmington in particular, averaged an annual total of 43.0 inches of precipitation from 1981-2010. Given the importance of rainfall to the relative humidity rate, its potential impact on adipocere formation and the deceleration of decay, its involvement in limiting insect access under aquatic conditions, as well as the high water table depths known to populate the Coastal Plain soils throughout Delaware (see Figure 9), the consistent precipitation in the area may prove to speed up the rate of decay, or conversely, slow it down if conditions prove right.

In order to continue the comparison between climatic conditions in Knoxville, Tennessee and Wilmington, Delaware, precipitation data between the two will be presented here as well. According to the data gathered from the "Comparative Climate Data: For the United States Through 2012" study conducted jointly by the NOAA, NESDIS, and NCDC in 2013, Knoxville sees 10 more days of precipitation of 0.01

inches or more. In regards to the average annual precipitation total, a study conducted by the U.S. Department of the Interior and the U.S. Geological Survey found that from the period of 1961-1990, Tennessee averaged an annual precipitation total of 52.98 inches (see Figure 8). Given the nearly 10 inch difference in annual precipitation totals, coupled with the differences noted in regards to relative humidity, it becomes clear that Tennessee does in fact represent more of a humid, sub-tropical climate than Delaware, reinforcing the need for decomposition studies specific to the environmental context displayed in the Delaware River Valley Region.

Lastly, although the information presented in the sections above regarding burial type and depth cannot be modeled specifically to Delaware, certain environmental data may be of use. As mentioned above, moist soils play a critical role in adipocere formation, especially the deeper one goes below the surface (Rodriguez 1997). Figure 9 presents water table data throughout the state of Delaware, which may prove to be of use if burials are found in areas with high depths to the water table, potentially leading to a greater preservation of body tissues (United States Department of Agriculture, National Resources Conservation Service 2012).

Elevation

In addition, Haglund et al. (1997) claim that depending on elevation, different carnivores may scavenge and disarticulate remains. If this is known to be true, the same principle can apply to insects and plant growth as well. Thus, in order to assess potential effects of differing altitudes on decomposition, a map of the varying elevations throughout Delaware is provided, derived from data extracted from the National Elevation Dataset, courtesy of the United States Department of the Interior's United

States Geological Survey/Topocreator (see Figure 10). Given that the highest point, Ebright Azimuth, is only about 450 feet above sea-level in Northern Delaware and seeing as to how the rest of the state shows elevations of 100 feet or less (United States Department of the Interior, United States Geological Survey/Topocreator 2014), it appears as if elevation will not be a dramatic factor involved in developing PMI standards specific to the state.

Exposed versus Shaded Remains

As Shean et al. (1993) have demonstrated, differences due exist between carcasses left to decompose in direct sunlight versus shaded areas. In times of warm temperatures, exposed carcasses display a faster progression through decomposition. In regards to Delaware, differences in temperature, specifically in regards to the average number of days above 90 degrees F, have already been discussed above. Although it is impossible to define shaded areas, some data has been collected in regards to the number of clear, partly cloudy, and cloudy days experienced annually. According to the joint NOAA, NESDIS, and the NCDC study in 2013, Delaware averages 97 clear days, 104 partially cloudy days, and 164 cloudy days per year. When these figures are compared to data collected in Knoxville, Tennessee, the report indicates 97 clear days, 107 partially cloudy days, and 162 cloudy days annually. These numbers are essentially equal. When compared across months, the numbers do not differ dramatically either. Thus, it appears that if decompositional differences are to be seen, they will be more the result of factors such as temperature (hot, cold, extent of temperature extremes), humidity, aridity, precipitation, differences in insect types, scavengers, and so forth.

Soil Type

Given the relationship between soil type and pH in regards to the deterioration of osseous material, a description of soil types in Delaware is warranted. A map of various formations and deposits throughout Delaware is provided in Figure 11 (Delaware Geological Survey 2010). In addition, Figure 12 depicts the soils found throughout Delaware (United States Department of Agriculture, National Resources Conservation Service 2012). This is provided in the hopes of understanding how soil moisture content and texture, in combination with pH levels, affects the rate of decay of bodies. Although fully buried remains will not be analyzed in this study, this particular data may prove to be of value when attempting to assess whether bodies deposited on ground surface layers demonstrate a greater degree of preservation compared to those in indoor and aquatic contexts.

Population Density

According to the United States Census Bureau (2010), Delaware is the 8th most densely populated state in the United States (see Figure 13). Bordered to the northeast by New Jersey, to the North by Pennsylvania, and to the West and South by Maryland, Delaware is within close proximity to multiple major urban centers including Philadelphia, Baltimore, and Washington D.C. As can be seen in Figure 10, the most densely populated areas in Delaware can be found in New Castle County, where Delaware’s most populated city, Wilmington, is located (2010). Newark, Delaware, the third most populous city in the state, is also located in New Castle County (2010). Dover, Delaware’s capital city, and the second most populous city in the state, can be found in Kent County, the middle most County in Delaware (2010). In addition, Figure

14 depicts the estimated population size of Delaware during the time of the last United States Census, totaling 897,934 (2010). Currently, the population of Delaware is estimated to have risen since then, totaling 925,749 in the present day (see Figure 14; United States Census Bureau 2014). A marked increase in population size every decade has been seen dating back to 1970.

Given the influence of population density on scavenger activity as mentioned above, it would appear that New Castle County would have the lowest likelihood of scavenger involvement with remains. Kent and Sussex Counties, especially in areas near the shore in Kent County and to the West of Dover, are more likely to have scavengers given their lower population densities and increased land area compared to New Castle County. However, Delaware is the 8th most densely populated state in the country, so the extent of the effects of scavengers can only really be determined once cases are examined. This data is really only of use as a guide to assessing potential impacts of scavengers around the state.

Chapter Seven: Research Questions and Goals

Through both quantitative and qualitative analyses, this research aims to address many questions and achieve multiple goals of varying subjects and scope. In regards to quantitative analysis, this study sets out to not only develop a region-specific approach to estimating time since death in the Delaware River Valley Region, but to also compare the results of this particular study to Megyesi et al.'s (2005) landmark study conducted utilizing data from various regions throughout the country, including evaluations of ADD versus PMI, and core versus periphery processes in regression equations. From there, the particular effects of variables such as environmental conditions, scene-specific factors, and depositional context on decay, and their usefulness in estimating time since death, can be evaluated. Qualitatively, this study sets out to better understand the decompositional changes which occur, in order to develop a more region-specific and precisely-defined set of decomposition standards, applicable to both outdoor surface and indoor depositions, as well as aquatic contexts. Lastly, this research also seeks to identify the particular pattern and progression of decomposition, as it applies to the Delaware River Valley Region, to develop a more accurate total body scoring system, as well as better inform the medico-legal community and aid in scientific forensic investigations. In total, it is hoped that by refining these methods and better understanding decomposition in the Delaware River Valley, as well as the various factors which alter it, forensic investigators in the region will have a more valid and reliable set of methods by which to estimate time since death, affirming the need for region-specific standards.

Quantitative Focus

Clearly, one of the main goals of this study is the development of a regression equation by which to estimate time since death in the Delaware River Valley Region. In recent years, multiple studies such as those conducted by Megyesi et al. (2005) and Heaton et al. (2010) have attempted to utilize a quantitative approach to estimates of time since death. Given the call by multiple studies, including those referenced above, to generate equations particular to more narrowly defined regions, this study aims to address this glaring need and gap in research.

However, this study also sets out to take the need for region-specific equations a step further by evaluating the model derived from Megyesi et al.'s (2005) seminal paper, "Using Accumulated Degree-Days to Estimate the Postmortem Interval from Decomposed Human Remains," and applying it directly to the data collected for this study. Based on the results of a comparison of the coefficient of determination, R^2, as well as a comparison of predicted versus actual ADD values developed utilizing the Megyesi et al. (2005) model and the model derived from this research, it is hoped that this approach will begin to illuminate answers to the question of whether or not Megyesi et al.'s work is applicable to the entire United States, or if more region-specific equations, with their own set of total body score systems, are indeed needed.

Moreover, this study not only seeks to develop a regression equation to estimate time since death, but it also attempts to evaluate the effectiveness of the use of accumulated degree days versus post-mortem interval days. The reason this particular approach is taken is to evaluate claims made by Megyesi et al. (2005) which states, "decomposition is best modeled as dependent on accumulated temperature, not time."

Specifically, the study claims that ADD accounts for more of the variation in decomposition than simply counting the number of days which have passed since the individual's expiration. Therefore, this study seeks to evaluate "time since death" in two separate manners, the first looks at PMI as the number of days which have passed between the "date last seen" and the "date recovered," while the second tallies the combination of elapsed time and temperature, as it is reflected in the number of accumulated degree days which have amassed during that same time frame. In order to evaluate the use of both approaches toward the estimation of time since death, two separate models will be derived, one utilizing accumulated degree days and the other, post-mortem interval days. This approach not only seeks to evaluate whether ADD or PMI best models decomposition, but also seeks to understand if this particular school of thought applies to the Delaware River Valley Region in particular.

Furthermore, given the dearth of studies conducted in aquatic environments, this research seeks to derive a regression equation which can not only be applied in cases of outdoor and indoor depositions, but also to those involving water contexts. Therefore, a separate regression equation will be developed for aquatic contexts in particular. From there, the amount of variation which each equation accounts for, will be compared to each other in order to determine if a regression formula for each particular depositional context is warranted, or instead, if a general equation applicable to all contexts is better suited to the Delaware River Valley Region.

Additionally, given the large amount of variation in decomposition, it is crucial that this study also seeks to determine if the variation seen can be understood by evaluating the effects of individual variables at play on scene, or determine if the effects of those variables cannot be separated out from each other, instead reflected jointly as inextricably linked to the temperature component of the accumulated degree days and the total body score. This particular research question derives from a theory developed by Stephen Nawrocki and Kristha Latham (2013), who claims that core and periphery variables exist in regards to decomposition. According to Nawrocki and Latham, the core processes and variables, such as temperature, humidity, and insect activity, can be recorded on scene and tracked back through to the point of death, while the periphery processes such as adipocere formation, excessive scavenger activity, and so forth, are too difficult to model (2013). Thus, given the interrelatedness of temperature with multiple periphery variables known to alter decomposition, this study seeks to determine if the effects of those variables can be identified separately, or instead, are inextricably tied together, the joint effects of which are reflected in the total body scores and the temperature component of the accumulated degree days.

In addition, since Mann et al.'s (1990) paper, multiple research studies have attempted to assess the impacts of various variables on decomposition, with some offering contradictory views. It is critically important that the effects of variables on decay is well known so that future studies can continue to refine quantitative approaches to time since death estimates using the relative impact, degree, number, and presence of variables to do so. This evaluation also extends to the need to validate whether differences in the rate of decay exist between depositional contexts. Therefore, this particular study will employ a dichotomous approach to make comparisons regarding the effects of variables on the rate of decay. The particular variables in question will be as follows:

A. Dirty vs. Clean House
B. Shaded vs. Exposed Remains
C. Trauma vs. No Trauma
D. Insect vs. No Insects
E. Scavenging vs. No Scavenging
F. Clothed vs. Not Clothed
G. Soil pH Below 5.5 vs. Soil pH Above 5.5
H. Supine vs. Prone
I. Supine vs. Seated
J. Supine vs. Hanging
K. Prone vs. Seated
L. Prone vs. Hanging
M. Seated vs. Hanging
N. Water Salinity Medium and Below vs. Water Salinity High-Medium and Above
O. Indoor Context vs. Non-Water Outdoor Context
P. Indoor Context vs. Water Context
Q. Non-Water Outdoor Context vs. Water Context
R. Sex: Female vs. Male
S. Age: Below Age 50 vs. Above Age 50
T. Stature: Below 6’0” vs. Above 6’0”

Lastly, by developing a quantitative approach to PMI estimation, it is hoped that the demands set forth by *Daubert* (1993), *Kumho* (1999), and the Federal Rules of Evidence (2000), calling for replicable, reliable, and valid methods with consistent results, scientific acceptance, and the determination of statistically-backed error rates (Dirkmaat and Cabo 2012), will be met. In conjunction with these federal mandates, this research can also address the needs outlined in the National Academy of Sciences’ (2009) report compelling the field to improve its methods and the samples upon which its standards are based, in order to demonstrate their validity, reliability, and accuracy, as well as provide statistical interpretations, confidence intervals, and error rates regarding its analyses.

Ultimately, it is hoped that this research will continue the strides made away from dated, typological approaches towards a more modernized, quantitative, and multivariate approach to modelling decomposition and the factors at play.

Qualitative Focus

Qualitatively, it is crucial that this research study identifies the particular decompositional changes which occur in the Delaware River Valley Region, as they are critically important to determining accurate total body scores, and ultimately, accurate estimations of time since death. Studies have developed and employed the use of generalized or region-specific decomposition standards in order to tabulate total body scores as applicable to their particular research efforts and regions of interest. However, those particular standards may not overlap completely with the decompositional changes seen in this region and thus may not be applicable, potentially invalidating the methods developed to estimate time since death in this study. For example, in the Megyesi et al. (2005) study, the standards utilized are based on decompositional changes that they associated with cases in their dataset, which spanned multiple regions. These observations of decomposition may be too general or incompatible with the changes observed in the particular area of interest in this study. Additionally, in the Heaton et al. (2010) study, they specifically state that they adjusted the standards developed in Megyesi et al. (2005), as well as Hobischak and Anderson (2002), so that they identified decompositional changes tailored to their particular aquatic environment, which ultimately led to a more reliable and precise equation to estimate time since death. Therefore, in order to combat any issues arising from the use of invalid standards, the decompositional changes across all of the cases included in the dataset will be analyzed, ensuring there is a complete understanding of the decay process as it occurs in this region. In total, the result will be the development of a total body scoring system which will more accurately reflect the pattern of decomposition as it applies to the Delaware River Valley Region. In this way, any time since death equation derived from data from this particular region, will more accurately model the specific decompositional changes which occur here. Given the difference in variables factoring into decomposition between outdoor surface, indoor, and aquatic contexts, it will also be determined if a different set of total body scoring system standards are needed for each depositional context.

Lastly, along the same vein, this study also seeks to identify the particular pattern and progression of decomposition, as it applies to the Delaware River Valley Region. For example: Does mummification begin first in the distal-most extremities? Does skeletonization start in specific areas of the face and progress from there? Given the environmental differences between this region and others throughout the country, identifying and recognizing these patterns may likely prove important to fine tuning the understanding of decomposition in the region and any standards derived from these observations. In the end, these determinations may be used to better inform the medico-legal community and aid in scientific forensic investigations.

Informing the Medico-Legal Community

After analyzing and refining these methods, developing a regression equation which incorporates an understanding of the variables at play, and arriving at a more informed understanding of the decompositional changes and patterns which occur in the Delaware River Valley Region, these results will be circulated throughout the medico-legal community in the area, in hopes of providing investigators with a more valid and reliable set of methods by which to estimate time since death. Additionally, given the decompositional analysis and “tips” to be provided to help identify specific changes and patterns, the study will assist Medical Examiners, pathologists, and forensic investigators in successfully identifying traits necessary to assigning a total body score. It is also anticipated that the insights developed in regards to key variables involved in decay will help the identification of critical factors on scene and guide investigations.

In total, by highlighting these key observations and better understanding decomposition in the region, as well as the various factors which alter it, it is hoped that the regression equation will provide more reliable and precise estimates of time since death, and therefore lead to a quicker transition in regards to tracking down leads, identifying suspects, and closing a case.

Chapter Eight: Methodology/Research Design

To begin, the study was broken down into two main components: a quantitative focus and a qualitative focus. Both components informed each other, making up critical aspects of the development of the time since death regression equation. The qualitative component focused on determining the specific pattern of decompositional changes which occur in order to inform the total body scoring system, while the quantitative aspect employed the use of a multivariate regression analysis incorporating statistically significant variables, total body scores, and accumulated degree days or post-mortem interval days, to create an equation by which to estimate time since death.

Hypothesis

Multiple studies conducted throughout North America have noted regional differences in the rate of decomposition of human remains due to the effects of various environmental, scene-specific, and depositional variables (Galloway et al. 1989; Mann et al. 1990; Komar 1998; Megyesi et al. 2005; Karhunen et al. 2008; Heaton et al. 2010; Parks 2011). However, to date, no such study, whether qualitative or quantitative, has been conducted in the Delaware River Valley region, comprising southeastern Pennsylvania, New Jersey, and Delaware. Given this dearth of studies, it is hypothesized that new insights regarding the progression of decomposition in this area, as well as the identification of key variables and the effects of depositional context on modelling decay, will be demonstrated.

Specifically, in regards to qualitative analyses, based on the particular environmental, scene-specific, and depositional variables inherent to the area, it is hypothesized that a distinct progression to decomposition will be demonstrated for the

Delaware River Valley region. As a result, a new total body scoring system, incorporating the specific decompositional changes and patterns of decay observed in this area, will need to be derived for the Delaware River Valley. Additionally, given the postulated differences in the decomposition process between depositional contexts, especially in regards to decay in non-aquatic versus aquatic environments, it is hypothesized that two separate total body scoring systems will need to be developed, one derived specifically for non-water outdoor and indoor cases and another for water cases. Lastly, it is hypothesized that precise descriptions of the decompositional changes and patterns representing the process of decay particular to an area and depositional context, reflected in the total body score system, will be one of the most important factors involved in accurately modelling decomposition and estimating time since death.

In regards to quantitative analysis, it is hypothesized that accumulated degree days will explain more of the variation in decomposition compared to post-mortem interval days, supporting similar conclusions in quantitative decomposition studies conducted in other regions. Furthermore, in addition to total body score, it is hypothesized that multiple variables, comprising both core and periphery factors and processes, will be demonstrated to have a statistically significant effect on the rate of decay. However, given the fact that their effects will be represented jointly in the total body score for each case, this particular discovery will further support the hypothesis regarding the critically important role played by accurate total body score descriptions in effectively modelling decomposition and estimating time since death. Moreover, based on differences in the factors altering decay in varying depositional environments, it is hypothesized that stratified analyses will highlight the existence of as-yet-unknown confounding factors which work to further complicate the estimation of time since death in aquatic environments and any models derived thereof. As a result, these stratified analyses will validate the development of separate time since death estimation models for non-aquatic and aquatic cases. Similarly, non-water outdoor depositions will be shown to produce the fastest rates of decay, followed by indoor and aquatic cases. Along the same vein, these stratified analyses will also serve to further support conclusions regarding the utility of accumulated degree days versus post-mortem interval days in estimating time since death. Lastly, and perhaps most importantly, by incorporating data into the model which are derived from cases in the Delaware River Valley, and utilizing a total body score system which is representative of the decay process observed in this area, it is hypothesized that this model will account for more of the variation in decomposition than that of the approach utilized by Megyesi et al. (2005). This particular discovery will not only serve to validate the development of region-specific decomposition models, but will also specifically highlight the applicability of the model derived in this study to cases in the Delaware River Valley.

Criteria for Inclusion

In order to evaluate decomposition using both quantitative and qualitative analyses, this study took an applied, actualistic, and retroactive approach to data collection, focusing on real-life forensic cases handled by the Delaware Office of the Chief Medical Examiner. In order to gain access to an appropriate sample size from which to draw meaningful conclusions and increase the statistical power of the dataset, past and present cases accessed from records comprising autopsy and investigator reports, photographs, and scene maps, were utilized. No discrimination was made based on biographical variables other than including only adult cases (with 16 being the cut-off) to protect against differences due to large body size discrepancies, thus allowing the inclusion of adult individuals of all sexes, ancestries, heights, and weights. In order to protect the confidentiality of human subjects, cases were assigned unique identifiers, with case numbers and names being redacted. Lastly, data accumulation efforts began at the Delaware Office of the Chief Medical Examiner in July of 2012 and ended in May of 2013.

In order to be included in the dataset, cases needed to conform to several criteria. First off, in order to develop as representative a sample as possible, a “fuzzy” keyword search was initiated for cases conforming to various stages of decomposition and subsequently grouped along those parameters, including all variations of the following terms: early, early-moderate, moderate, moderate-advanced, and advanced decomposition, as well as mummification and skeletonization. These specific categorizations were extracted from the verbiage included in autopsy reports written by the Medical Examiners. Given the “Lotus Notes” database system employed by the Delaware Office of the Chief Medical Examiner, these keywords could be inputted into the search query box and all autopsy case reports including them would be shown.

Secondly, only cases which provided both a “date last seen” and “date recovered” were evaluated. This particular criterion was strictly enforced in order to maintain as accurate an estimate of the post-mortem interval as possible. If a known post-mortem interval was not provided, then there would be no way to determine the time required to produce specific decompositional changes or calculate the effects of specific variables and contextual factors on the rate of decay, critical components in the development of a time since death equation. Furthermore, the post-mortem interval derived from the date last seen and date recovered was critical to summing the total amount of accumulated degree days to which each particular case had been exposed.

Moreover, after having identified cases exhibiting relevant decompositional changes, as well as a known post-mortem interval period, in order to evaluate the effects of depositional context on decomposition, cases were further broken up into three main groups: non-water outdoor, indoor, and aquatic contexts. As a whole, the dataset consisted of cases representing a wide variety of conditions, including all stages of decay, various depositional contexts, and exposure to varying environmental conditions.

Criteria for Exclusion

After populating a list of potential candidates for inclusion into the dataset, each case needed to be read through in order to determine if it demonstrated any characteristics which would confound analysis or require extensive subjective interpretation. Given the fact that this study attempted to maintain as objective an approach as possible, areas where subjective evaluations could be avoided, were avoided. In particular, if the autopsy report or forensic investigator records on a case were not detailed or extensive enough to warrant inclusion in the dataset, they were excluded. This also included those cases where descriptions were poor and no photographs were available to make determinations regarding relevant variables.

As per the usual in studies incorporating multivariate regression analyses, outliers were identified by SAS 9.3, the statistical program used for analysis. In order to remove the possibility of outliers influencing the dataset, the top five and bottom five percentile of cases (not *percent* of cases) seen to poorly fit the regression line, and thus deemed outliers, were excluded from analysis. In this way, the dataset used for analysis could counterbalance any potential effects from outliers.

Given the fact that the dataset was working with accumulated degree days in one model and post-mortem interval days in another, differences in the top and bottom five percentile of cases were observed between both models. It is important to note that *percentile* is different from *percent* as the former reflects a ranking of those cases outside of the normal range. The top and bottom five percentile of accumulated degree day totals, which corresponded to values above 3600 ADD or below 30 ADD, only required the removal of five total cases, while the same percentile in regards to post-mortem interval days, which corresponded to values above 174 days or below 3 days, required the removal of 11 cases.

Continuing on, as mentioned above, a very important factor in excluding cases dealt with the availability of a known "date last seen" and "date recovered." If this particular information was missing, these cases were excluded from entry into the dataset. In the same vein, cases which displayed very high post-mortem intervals above four years were excluded from consideration. The reason for this exclusion deals with the fact that once the skeletonization phase has reached its dried out and fragile conclusion, no additional stages beyond that point exist. Therefore, if a case was observed to be completely skeletonized, dried-out, and fragile, and the associated post-mortem interval was several years in length, that particular case would only serve to skew the dataset towards that higher value. In essence, these cases functioned as outliers and warranted exclusion.

Additionally, on some occasions it was observed that the accumulated degree days or post-mortem interval days on a case did not correspond with what was typically seen in regards to the decompositional changes expected by that point, especially in comparison with cases displaying similar accumulated degree days. Therefore, under such circumstances, those cases were removed from consideration in the data analysis as well.

Similarly, given the complications regarding decelerating the rate of decomposition in cases exhibiting large degrees of saponification, those case records which displayed extensive adipocere development were excluded. Under these circumstances, it appeared as if the adipocere prevented the disintegration of tissues to the point of skeletonization, instead presenting a fleshed appearance, covered in adipocere and mud. These observations did not correspond to the model, which is developed from non-adipocere filled cases, and therefore required removal.

Another point of exclusion dealt with exposure to multiple depositional contexts. In particular, if a case was seen to have washed ashore, given the mix of contexts to which it would have been exposed, it was excluded from the dataset. Given the fact that one could not predict the length of time spent in the water versus the time spent on land, it was impossible to calculate the accumulated degree days to which the body had been exposed, especially considering the temperature differences between water and on land. This also complicated matters concerning which total body score system to utilize, as scores differed between water and non-water cases. The variables at play in both contexts also differ, introducing another confounding aspect. Therefore, exclusion was certainly warranted.

Lastly, continuing on with the discussion of aquatic cases, water temperature data for the calculation of accumulated degree days was hard to come by. Given the need to determine the exact temperatures to which the bodies had been exposed to in water, only those cases which could be matched up with records from a nearby weather station in the same body of water, were included in the dataset. All other cases lacking accurate water temperature data were subsequently excluded. If this particular step was not taken and the water temperature records from nearby bodies of water were utilized in place of the missing data, this study would have to have made undesirable assumptions regarding similarities in water temperature in similar regions regardless of the characteristics (salt, fresh, brackish, etc.) of the bodies of water being compared. Thus, in order to avoid assumptions claiming, for example, that the ocean temperature recorded in an area was the same as that of a nearby man-made pond, these exclusions were necessary.

Variables of Interest

In addition, in alignment with the methods of studies in other regions, and as identified by Mann et al. (1990) and all subsequent research, certain environmental and scene-specific variables were recorded from case files based on their presumed effect on the rate of decay. Those variables are discussed in detail above (see Chapter Five). Their inclusion in the dataset was based largely in part on whether or not historical records existed recording their presence, absence, and number, or if they were noted in sufficient detail in autopsy and forensic investigator reports and photographs. Some variables, such as the percentage of relative humidity, have not been recorded in sufficient detail by any reliable source, while others, such as plant activity and embalming, were not of particular interest to the study. Therefore, those variables were excluded.

In regards to the variables of interest to this study, based on the requirements stated above, they were as follows: temperature (measured in accumulated degree days), post-mortem interval length (measured in days), total body score (based on quantified observed decompositional changes), precipitation (including rain, melted snow, and so forth), insect activity, scavenger activity, penetrating peri-mortem trauma, clothing, shade versus sun exposure, body position, soil type, soil pH, dirty versus clean houses, water salinity, as well as aspects of the biological profile, including age, sex, and stature. Based on the particular depositional context, some variables were applicable in some circumstances, while others were not. Tables nine through 16 summarize the variables recorded specific to each depositional context.

To demonstrate how each variable was collected and reconfigured into a quantifiable form in order to evaluate their effects on the rate of decay, they will be discussed individually below. Before delving into specifics however, it is crucial to note that given the need to quantify the data collected in some format, while also recognizing the fact that differing degrees of each variable may play varying roles in regards to altering the decomposition process, point systems were devised to account for these aforementioned considerations.

Temperature: Calculating Accumulated Degree Days

As stated above, some researchers (Megyesi et al. 2005; Simmons et al. 2010a; 2010b; Heaton et al. 2010; Nawrocki 2011) currently believe that the principle of accumulated degree days explains more of the variation in decomposition, compared to a simple measure of time quantified in the form of the post-mortem interval period. In order to evaluate such claims, two approaches were taken based on whether the cases were derived from non-water outdoor and indoor contexts or aquatic contexts.

In regards to the outdoor and indoor cases, retrospective temperature data was accessed utilizing the National Oceanic and Atmospheric Administration's National Climatic Data Center, Global Historical Climatology Network (2013). This database of historical temperature records compiles daily maximum and minimum observations of temperature throughout a number of National Weather Service Stations situated throughout the country. Dozens of such weather stations exist in the State of Delaware. Based on the exact location in which a corpse was found, which was recorded in forensic investigator reports, the closest National Weather Service Station with temperature records during the post-mortem period of interest, was mined for data. Starting on the date in which the body was recovered, back until the date in which the individual was last seen, the minimum and maximum temperatures for each day were recorded and then averaged. The average for each day was then summed over the post-mortem period in order to calculate the total accumulated degree days, in degrees Celsius, to which the corpse was exposed. No corrections were performed on any of the temperature data based on the distance from the site to the weather station, or any other variable.

In regards to aquatic conditions, a similar approach was utilized. Unfortunately, the data was much harder to come by. Given the results of Champaneri's (2006) research, which found that the decomposition of rat carcasses in temperature-controlled aquatic environments was affected by temperature much like terrestrial decomposition demonstrates, the need developed to access water temperature records to calculate accumulated degree days. Utilizing surface ambient temperatures would not suffice, as those temperatures do not accurately reflect the heat-energy units to which bodies deposited in water were exposed to. In turn, the resulting predictive equation would not explain much of the variation observed. Thus, the decision was made to use actual water temperature data.

However, given the difficulty in placing water temperature recording stations at the same intervals as weather stations on land, many areas lacked temperature records. This was especially the case in situations where bodies were found in small lakes, ponds, and streams. Therefore, as described above, many of these cases were excluded from the dataset and analysis. Fortunately, water temperature data was eventually procured from a variety of sources including the United States Department of Interior's United States Geological Survey, National Water Information System (2013), the National Oceanic and Atmospheric Administration's National Data Buoy Center, Chesapeake Bay Historical Marine Database (2013), and the National Oceanic Atmospheric Administration's Center for Operational Oceanographic Products and Services, Tides and Currents Historical Water Temperature Records Database (2013). Once this data was procured, the same approach utilized in regards to the calculation of accumulated degree days in outdoor surface and indoor contexts was utilized.

However, regardless of depositional context, one caveat of note should be disclosed. Given the fact that accumulated degree days represent the heat-energy units available to drive biological and chemical processes, such as bacterial and larvae growth (Megyesi et al. 2005), a "base temperature" exists representing the temperature under which these processes stop. As noted above, optimal temperature ranges exist for both bacterial and insect activity. Below the minimum range, this activity not only becomes greatly retarded, but ceases altogether (Micozzi 1997). Despite the use of bases of six and 10 degrees Celsius by a number of forensic entomological studies (Byrd and Allen 2001; Donovan et al. 2006), Vass et al. (1992) state that due to the concentration of salt in the human body, decomposition occurs down to zero degrees Celsius. In fact, Higley and Haskell (2001) demonstrate that the most accurate time since death equations utilize a base temperature of zero degrees Celsius or 32 degrees Fahrenheit, corresponding to the freezing point. Therefore, in this study, accumulated degree days were calculated using average daily temperatures above zero degrees Celsius. In cases where the minimum daily temperature was lower than zero degrees Celsius, the temperature was always recorded as zero rather than as a negative value. This approach to accumulated degree day calculation is the same as that employed in Megyesi et al. (2005).

In total, the dataset averaged 510.1 accumulated degree days, with a range from 45.3 to 3546.7, and a standard deviation of 756.7 ADDs. Table 17 depicts the frequency and range of accumulated degree days included in the dataset in a histogram format.

Post-Mortem Interval Length

For each particular case included in the dataset, the post-mortem interval length, measured as the number of days between the "date last seen" and the "date recovered," was known. The PMI period was determined by forensic investigators upon identification of the unidentified remains. In turn, the last known history of the individual was tracked up until the point they were reported missing. As a result, one could simply calculate the difference between the date the individual was last seen and the date they were recovered, in order to determine the post-mortem interval length. Obviously, as described above, this determination played a factor in the summation of accumulated degree days based on historical temperature records over the post-mortem interval period determined for each case.

In regards to the figures derived from this dataset, the mean post-mortem interval length was 28.1 days, with a standard deviation of 35 and a range from four days after death to 169 days post-mortem. Table 18 depicts the frequency and range of post-mortem interval days included in the dataset in a histogram format.

Developing the Total Body Score

The total body scoring system was derived in part from two sources: for non-water outdoor and indoor cases, the Megyesi et al. (2005) standards were utilized, while the standards produced by Heaton et al. (2010) were consulted for aquatic cases. A distinction was made between these two standards given the recognition that these varying depositional contexts present their own set of variables which alter decay in different ways, thus producing different decompositional changes. Importantly however, these standards were then adapted and changed to better fit the specific decompositional changes and patterns observed in the Delaware River Valley Region. Assuming that the specific environmental and ecological factors in the region would alter the decay process, a refined scoring system was needed to not only better represent decomposition in the area, but to develop a predictive equation more applicable to this region. Based on the total body score descriptions created, evaluations could be made regarding whether or not a distinct progression to decomposition exists in the Delaware River Valley.

In order to do so, this study employed the use of several key qualitative methods to build the quantitative scoring system. Those methods included the use of first-hand observations of decomposition in a variety of stages and environmental settings, analyses of patterns based on descriptions of decompositional changes in each decompositional stage as defined by autopsy and forensic investigator reports, examination of scene photographs, and consultation with various forensic investigators, medical examiners, and forensic anthropologists.

In particular, the descriptions used in the autopsy, forensic investigator, and supplemental investigation reports, as well as observations made from scene photographs, played a significant role in shaping the descriptions developed for the total body score system utilized in this study. The most valued information pertained to the extent and location of bloating, marbling, skin and hair slippage, degloving, skin discoloration, purging of fluid, autolytic and liquefaction changes to organs, wrinkling of the hands and feet, development of “washerwoman” changes, location and amount of soft tissue present, percent of bone exposed, extent of dried, leatherized, and mummified skin, degree of scattering of remains, and indications and scope of insect and scavenging activity.

Based on these valuable descriptions, a set of standards particular to non-water outdoor and indoor, as well as aquatic depositional contexts, was created. Each set of standards was divided up into the three main areas of the body: head/neck, trunk, and the limbs. For the sake of clarity, in regards to the three subsets of the body making up the total body score, the genitalia, clavicles and upper ribs were defined as part of the torso. From there, each general stage of decomposition was identified, divided up into sub-stages, and assigned their own specific score. Therefore, when evaluating decomposition, one need only match the observed decompositional changes in each area of the body to their assigned scores, and subsequently sum those figures to calculate the total body score.

In turn, the Megyesi et al. (2005) and Heaton et al. (2010) standards were altered to more accurately reflect the decomposition process in this specific area. When each specific stage and sub-stage was identified, scores were attributed to each phase of the process, ranging from three to 43 for non-water outdoor and indoor cases and three to 29 for water cases. By utilizing a qualitative analysis of the decomposition process, the result was a new set of standards by which to quantitatively score the decompositional changes observed and ultimately, predict time since death.

As it relates to the accumulated degree day group in this dataset, the combined weighted total body score range spanned between eight and 39 points on a 3-42 scale. The average total body score attributed to the cases equaled 17.2, with a standard deviation of 6.9. Table 19 depicts the frequency and range of weighted total body scores included in the ADD dataset in a histogram format. In terms of subsets, aquatic cases ranged from eight to 19.5 on a 3-29 scale. The average equaled 11.8, with a standard deviation of 2.7. The combined outdoor and indoor case subset ranged from eight to 39 points on a 1-42 scale. The mean averaged at 17, with a standard deviation of 7.8.

In regards to the post-mortem interval day group, the combined weighted total body score also averaged 17, but the standard deviation was calculated to be 6.8. The total body scores also ranged from eight to 39 on a 3-42 point scale. Table 20 depicts the frequency and range of total body scores included in the PMI dataset in a histogram format. The aquatic subset ranged from eight to 18 on a 3-29 scale. The average equaled 11.6, with a standard deviation of 2.4. On a scale of 3-42, the combined outdoor and indoor cases ranged from eight to 39 points, averaging 17, with a standard deviation of 7.5.

Precipitation

In addition, precipitation totals over the course of the post-mortem interval period were collected. This particular variable was of interest in order to determine if the effect of water, not only in the form of accelerating or decelerating decomposition, but also in regards to detracting insect oviposition, scavenger access, promoting skin sloughing and adipocere development, and so forth, was apparent. Also, although the effect of rain in cases of deposition in water and in indoor contexts was assumed to be negligible at best, it was collected in such cases anyway, mostly due to the fact that the data was available.

In order to collect data regarding precipitation totals, both rain and melted snow totals were summed for each day. These particular figures were collected from the same source in which the historical temperature records were accessed: the National Oceanic and Atmospheric Administration's National Climatic Data Center, Global Historical Climatology Network (2013). In addition to historical temperature data, this database provides information regarding daily precipitation totals, and occasionally, evaporation and soil temperature records.

As was the case for temperature data, the nearest National Weather Service Station was tapped for precipitation totals. Starting on the date in which the body was recovered, back until the date in which the individual was last seen, the amount of rain and melted snow was measured in inches and summed over the course of the entire PMI period. In most cases, the same weather station was utilized for both temperature and precipitation figures. In cases where the same station was not used, it was due to incomplete or missing precipitation numbers. The next nearest National Weather Service Station was accessed to fill in when necessary.

In total, precipitation numbers varied throughout the dataset, mostly related to the differences in post-mortem interval length. The lowest sum was zero inches of rain, with the highest equaling 35.2 inches. More specifically, in the accumulated degree day group, the average total was 4.3 inches, with a standard deviation of 6.1 inches. In regards to the post-mortem interval day group, the average was 3.9 inches, with a standard deviation of 4.7 inches.

Insect Activity

In order to judge the presence of insect activity, a number of sources were used. Autopsy reports were often good sources of information as they not only noted the physical presence of insects and casings, but also any evidence of insect activity in the form of tissue consumption. Forensic investigator reports were also extensively used for the purpose of determining if insect activity and their artifacts were observed on scene. Lastly, photographic evidence from scenes was examined to determine if insect activity was present when autopsy or investigator reports failed to make mention of it.

In order to quantify the presence or absence of insect activity and determine its effect on the rate of decay, as well as any potential correlations to the total body score, points were assigned based on the degree of insect activity observed. This particular method was utilized to not only quantify insect presence, but to also acknowledge the differences between the beginning stages of insect involvement compared to infestation and the end stages of activity. Thus, in order to do so, the following scores were developed based on autopsy and investigator reports, as well as examination of scene photographs: 1). Zero points for the absence of insect activity and any signs of their presence, 2.) One point for insect activity, 3.) Two points for insect infestation or significant insect activity in the area, 4.) Three points for artifactual evidence of their presence in the form of casings or dead insects. This last score was included to acknowledge the fact that when this particular point in time is reached, insects have already consumed tissues and decomposition has progressed relatively far along in the process. Therefore, the score of three reflects insect activity which has already happened, as opposed to that which was never observed, demonstrated in cases where there is a complete and total absence of any signs of insect activity. Given the potential for differential activity in various areas of the body, as well as differential preference for natural orifices, each of the three main body areas (head/neck, torso, and limbs) was scored. In total, the scoring system is believed to accurately capture the degree, presence, or absence of insect activity throughout the body.

Importantly, if a particular area showed both insect activity and insect artifactual evidence, it was scored as “present” to account for the effect of the continual breakdown of tissue by the insects present on the body.

Moreover, in regards to insect activity seen on overlying clothing and not on the body itself, the insect activity was scored as “absent,” given the inability to directly confirm their influence on the breakdown of body tissues. In this way, the breakdown of tissue is prevented from being incorrectly attributed to insect activity if no such direct evidence is present.

Based on these criteria, for the accumulated degree day group, 36 total cases demonstrated no evidence of insect presence at any point in time. Out of those 36 cases, 21 were from aquatic contexts. Additionally, out of the remaining 15 cases in which no insect activity was seen, all but three were found in indoor contexts. Therefore, the majority of non-water outdoor depositions demonstrated evidence of insect activity.

In terms of the post-mortem interval day group, 31 cases showed no evidence of insect activity of any kind. The majority of cases exhibiting no insect presence were found in the water, 15, and indoors, 14, once again demonstrating the presence of insects in non-water outdoor contexts.

Scavenging Activity

Once again, evidence of scavenging activity was noted in both autopsy and forensic investigator reports through examination of bite and chew marks, gnawing, and scratches. Indications of scavenging were relatively difficult to detect via photographic evidence, given the need to assess bites and scratch marks. Nonetheless, photographs were consulted as needed.

Although often synonymous with carnivore activity, the presence of scavenging activity was defined to include any evidence of manipulation of the body tissues or bones by any animal, regardless of if on land, indoors, or in water. This particular decision was made to reflect the potential effects of fish, crustaceans, domesticated pets, and the like, and allow a direct comparison between outdoor, indoor, and water cases.

As was seen with a number of the variables examined by this research, indications of scavenging activity were noted using a binary system. When scavenging was noted, a score of one was attributed to the case, while no evidence of activity received a score of zero. In this way, scavenging activity could be quantified and evaluated in regards to its effects on the rate of decay and to the total body score.

In terms of total numbers, compared to the degree of insect activity observed, indications of scavenging were no more equal across contexts. In the accumulated degree day group, although 13 of the 20 non-water outdoor cases, and 13 out of 23 aquatic cases showed no signs of scavenging, only one indoor case out of 37 showed indications of scavenging. In that particular case, domesticated pets within the home consumed parts of the soft tissue. This may reflect the unwillingness of domestic pets to consume tissue until a number of days have gone by.

The same general trend was seen in the post-mortem interval day group as well, with only one out of 39 indoor cases showing indications of scavenging. The outdoor and aquatic deposition cases were split relatively evenly.

Penetrating Peri-Mortem Trauma

In order to evaluate claims regarding the preference of insects for traumatic areas of the body and thus, quicker access to the tissues and internal organs subsequently accelerating decay, evidence of penetrating peri-mortem trauma was collected. Any evidence of penetrating trauma occurring at or near the time of death, not related to insect or scavenging activity, was noted, including gunshot and sharp force wounds. Scratch and superficial cut marks were not deemed to be penetrating trauma given the fact that their presence did not provide quicker access to the internal aspects of the body.

Given the potential for acceleration of decomposition, penetrating peri-mortem damage, as evidenced in the autopsy or forensic investigator report, was recorded. Abrasions, contusions, or areas of hemorrhage not caused by penetrating injuries were not counted as penetrating peri-mortem trauma, as they are not directly related to facilitating insect access to the remains or accelerating decomposition, and may have been caused post-mortem or as a result of insect activity. Additionally, unless a penetrating peri-mortem defect was clearly noted in the bone, if the area being scored was mostly in a skeletonized state, penetrating peri-mortem trauma was scored as “N/A” to reflect the inability to make a judgment regarding the presence of trauma.

As was the case for quantifying the degree of scavenging activity, a binary score was utilized, with zero indicating no trauma, and one demonstrating the presence of penetrating peri-mortem trauma. Cases displaying scores of “N/A” were not assigned scores.

As observed in this dataset, penetrating peri-mortem trauma was not apparent in most cases. In fact, in both the accumulated degree day and post-mortem interval groups, only nine cases in each dataset showed any signs of penetrating injuries. Of all contexts, those found in non-water outdoor contexts showed the most evidence of trauma, often related to suicidal gunshot wounds.

Clothing

As discussed above, varying opinions exist regarding the influence of clothing on the rate of decay. In order to examine that relationship, the presence of clothing on the body was quantified. As usual, forensic investigator reports noted the clothing left on the body. This information was also discussed in detail in the introductions provided in autopsy reports. Photographic evidence was consulted when necessary. Based on those descriptions, the clothing located on the body was able to be scored.

In order to account for different clothing types, scores were assigned based on the thickness and ability of the material to provide thermal insulation. Additionally, given the fact that different clothes are worn on different areas of the body, clothing scores were assigned for the head, torso and arms, legs, and feet. In order to account for layering and thus, added protection from ambient temperature, insects, and scavenging activity, if multiple layers were observed, each layer was scored and a total was calculated for that particular area of the body. The scores from each area were subsequently totaled for an overall clothing score. The scoring system is described below and summarized in Table 21.

For the head, scores were straightforward given the limited scope of coverings available. In cases where hats or nightcaps were seen, one point was assigned.

For the torso, given the variety of clothing options available, various scores had to be assigned. Blouses, t-shirts, shirts, and sheet coverings were attributed scores of one. Given the lighter nature of nightgowns and tank tops, they were scored as 0.75, while bras were scored as half a point. Given the greater area covered, insulating effects, and thickness of the material, long-sleeve shirts, thermal shirts, sweaters and sweatshirts, as well as quilts and blankets, were given scores of two. Lastly, jackets of all types were scored as three.

The legs, which were not included with the feet, were also complicated to score given the presence of multiple layers. All shorts, boxer type undershorts, robes, nightgowns, and legs covered by sheets, were scored as one point. Underwear and panties also received a half point. Conversely, pants, jeans, sweatpants, pajama bottoms, thermal underwear, and bodies covered in blankets or quilts, were scored as two.

Lastly, in regards to the feet, bodies found wearing both socks were assigned scores of one. Occasionally, bodies were found covered with a sheet, which was also scored as one point. Given the greater protection afforded by sneakers, boots, and shoes, they were attributed two points. Oftentimes, only one shoe would be found on the body, thus gaining only one point. One sock found on the body also received half credit, or half a point. Sandals received half a point as well.

Although this particular scoring system was much more complicated than the binary system used for most other variables, it was designed specifically to account for the protection which clothing provides from the environment, temperature fluctuations, sun exposure, and insect and scavenging activity. It also provided a large scale by which to quantitatively evaluate the effect of clothing on decomposition, as various amounts and degrees of coverings could be evaluated.

When the amount and presence of clothing was scored, it was observed that the overwhelming majority of cases were found clothed in some manner for both the accumulated degree day and post-mortem interval day groups. The accumulated degree day set contained 13 individuals found completely nude and four wearing only one small piece of clothing. The PMI group showed 12 completely nude corpses and five bodies wearing one piece of clothing. As mentioned above, some individuals were found under sheets, blankets, or quilts, which was factored into the assessment of clothing score. Although some may argue against the inclusion of such cases, as Megyesi et al. (2005: 2) state, "While this type of unusual treatment could introduce error into the sample, they represent types of cases found in the practices of forensic investigators nation-wide and therefore serve as realistic tests for any method of PMI estimation." Therefore, they were included in the dataset.

Shade versus Sun Exposure

In regards to the exposure of bodies to sun versus shaded conditions, forensic investigator reports and photographs were consulted. In these reports, notes would be taken regarding the final location in which the body was recovered. Oftentimes, observations were recorded as follows: "The body was found underneath a thicket of brambles" or "The corpse was found snagged to a wooden plank beneath the Chestnut Street Bridge." Based on these descriptions, determinations could be made rather easily regarding the degree of exposure of the body to sun or shade. In order to visually confirm these observations, photographic evidence of the scene was utilized. For the most part, the photographs were clear enough to distinguish the context and conditions to which the bodies were exposed. When unavailable however, the forensic investigator reports were relied on solely.

Obviously, these particular observations were more applicable to bodies found on land. Given the tendency of corpses to move along waterways depending on tides and currents, this particular variable was not emphasized to any great extent in water cases. Although the data was collected in aquatic contexts, not much was expected in the way of results for the reasons just mentioned.

Lastly, in order to transform this data into a quantifiable format to facilitate evaluations regarding its impact of the rate of decay, a binary code was used. In this particular case, bodies exposed to the sun were marked as having a score of one, while those who did not receive sun exposure were marked as zero.

In total, the majority of outdoor corpses were located in the woods or fields. Given the cover provided by tree canopies, as well as the protection afforded by brambles, thickets, and so forth, 16 out of 20 cases in the ADD group, and 15 out of 18 cases in the PMI group were shaded from direct exposure to the sun. On the flip side, cases found in water, regardless of the group, were normally completely exposed to the sun, unless snagged under a bridge or weighed down.

Body Position

Extraction of data pertaining to the position of corpses upon recovery was relatively straightforward. In particular, this determination was made based on observations taken from forensic investigator reports and scene photographs. In these reports, investigators would note whether the corpses were recovered in prone, supine, hanging, or seated positions, as well as if they were found lying on their backs or to a particular side. These observations were then extracted from the reports and included in the dataset. In order to substantiate these claims, scene photographs were consulted to confirm the body position.

In regards to quantifying the effects of differences in body position on the rate of decay, scores were attributed based on the results of previous studies analyzing decomposition in a variety of positions (Early and Goff 1986; Goff 1992; Aturaliya and Lukasewycz 1999; Shalaby et al. 2000). Overall, it appears as if supine and prone bodies are the quickest to decompose. Therefore, these cases were scored highest. Following that are bodies found lying on their sides. Seated cases were next in the sequence, given the mix of vertical and horizontal placement of body parts. Lastly, vertically-positioned bodies appear to be the slowest to decompose, especially those found in a fully suspended state as a result of hanging. Thus, they were attributed the lowest scores in the analysis.

As it applied to the dataset, regardless of group, more often than not bodies were found to be in supine positions. Prone-positioned bodies followed next, with a handful of cases containing bodies lying on their sides, seated, or hanging. In water contexts, bodies were most often seen in the prone position, although a number of cases were deemed “Unknown,” given the fact that the body had been moved prior to the arrival of the forensic investigator.

Soil Type

Since 1899, the United States Department of Agriculture’s (USDA) Natural Resources Conservation Service has been publishing soil surveys from across the United States. Currently, these soil surveys are not only archived as PDF files, but they are digitally accessible utilizing the USDA’s Web Soil Survey (2013). The Web Soil Survey is an interactive tool which allows one to access current tabular and spatial data and create a custom soil report in the particular area of interest.

By utilizing this service, this study was able to access the specific soil types located in the area in which each specific case was found. In order to do so, each County in Delaware was designated as the specific area of interest in the soil survey. This in turn produced a detailed soil map of each County, showing the soil types throughout. From there, each case was found on the soil survey map based on the location specified in forensic investigator reports, thus identifying the soil type in the area in which each body was recovered.

In regards to the quantification of soil types to allow the determination of their effect on decomposition, categories were created for each and subsequently compared to one another. Obviously, given the location of soil environments, information could only be collected from those outdoor cases found lying on the soil ground surface. It should also be noted that occasionally, soil surface type in the particular area in which the body was found, was unknown. In those situations, the soil type was marked as “Unavailable.” When this limiting criterion is coupled with the limited availability of soil data, information could only be collected on 9 cases in the ADD group, and 8 in the PMI group. Of those cases, only four general soil types were noted, including: loam, sandy loam, silt loam, and moderately decomposed plant material. Each of those soil types were assigned scores ranging from one to four, respectively. Of those in the accumulated degree day set, four were found on sandy loam, three on silt loam, one on loam, and one on moderately decomposing plant material. In regards to the post-mortem interval group, four were found on sandy loam, three on silt loam, and one on loam.

Soil pH

In terms of the collection of soil pH data, the aforementioned Web Soil Survey tool (2013), offered by the United States Department of Agriculture’s National Resources Conservation Service, was employed. Whenever information was gathered regarding soil type, the Web Soil Survey also provided the specific pH of the soil in that area. In this way, data regarding both soil type and pH were able to be collected simultaneously. As in the collection of information pertaining to soil type, occasionally data was missing in the particular area in which the body was found, requiring soil pH for that case to be listed as “Unavailable.”

In order to evaluate the findings of Nielsen-Marsh et al. (2007), who argue that an increase in bone destruction is observed under pH levels of 5.5, coupled with the fact that no soil types were designated as basic, outdoor surface cases were grouped based on whether or not the soil type in which they were found corresponded to pH values above or equal to/below that threshold. By doing so, the cases could then be quantified in a binary fashion using a code of zero or one.

Of the nine total surface depositions in the accumulated degree day group with available soil data, seven of those soil types had pH levels above 5.5, while only two were at or below that threshold. The remaining seven cases had soil types and pH levels which were either unknown or unavailable.

The PMI group contained seven cases deposited on soils with a pH level above 5.5 and only one case found on sandy loam with a pH level of 5.5. A total of six cases had soil types and pH levels which were unknown or unavailable.

Dirty versus Clean Houses

In order to determine whether or not the state of cleanliness of a residence has any impact on the rate of decomposition, data was extracted regarding whether or not individuals were found in clean versus dirty houses. Once again, this determination was made based on forensic investigator reports and observations made from scene photographs. In cases in which houses were in a state of disarray, this was noted in investigator reports. In those instances where houses were clean, investigators more often than not, did not note the state of cleanliness. This insight was determined based on discussions with forensic investigators and examination of scene photographs. Therefore, when no mention of the state of cleanliness was made in the reports, it was assumed that the residence was clean. This was subsequently confirmed through visual examination whenever possible.

Obviously, given the fact that no clear distinction exists between both categories, some decisions had to be made on the part of the author and investigators regarding exactly what constitutes a "clean" versus "dirty" residence. Thus, a loose criterion was applied to those cases which would constitute as being in a "dirty" house. In particular, if investigators used the word "dirty" or a similar term to describe the residence, it was classified as such. Additionally, based on scene photographs, if the residence was seen to be in a state of disarray or covered in garbage, it was classified as "dirty." The author was hesitant to use the presence of insects as a marker of a "dirty" house for obvious reasons. When no decision could be made, the state of cleanliness was marked unknown.

Although classification of these categories required some effort, the quantification of these conditions was relatively straightforward. As has been demonstrated in all of the variables corresponding to the presence or absence of a specific factor, a binary code was utilized to quantify dirty versus clean residences.

In terms of total numbers, indoor cases in the accumulated degree day group were described as "dirty" in eight out of 37 instances. The remaining 29 were deemed not dirty or "clean." The post-mortem interval group also showed eight cases deemed "dirty," with 31 cases in "clean" residences.

Water Salinity Level

Given the purported ability of high salt concentrations to limit bacterial activity, data regarding water salinity levels was collected for aquatic cases. In order to do so, the National Oceanic Atmospheric Administration's Center for Operational Oceanographic Products and Services, Delaware Bay Salinity Nowcast database was accessed (2013). This particular federal website provides information regarding salinity levels in the

Delaware River, Chesapeake and Delaware Canal, Delaware Bay, and the Atlantic Ocean off of the coast of Delaware. The salinity levels range from zero to over 35 practical salinity units (PSU), with a score over 32 PSU usually indicative of levels near or off the coastline.

Given this information, several salinity categories were created, as demonstrated in Table 18: Freshwater (0 PSUs), Low (0-5 PSUs), Low-Medium (5-10 PSUs), Medium (10-15 PSUs). High-Medium (15-20 PSUs), Low-High (20-25 PSUs), High (25 and 32), and Open Water (32 PSUs and above). All cases found in man-made ponds, lakes, and streams were assigned "Freshwater" scores. All cases found off of the coastline or in the Atlantic Ocean were deemed to be "Open Water" cases. After having placed each case into its respective group, all eight groups were assigned a score ranging from freshwater equaling zero and open water equaling seven, respectively (see Table 22). In this way, salinity levels could be examined for their potential effect on altering the rate of decomposition and the proportion of variation in estimates of time since death explained by differences in salinity.

Based on the description provided above, water salinity levels for aquatic cases in the ADD group were broken down as follows: one in "freshwater," seven in the "low" level, four in the "low-medium" range, eight in the "medium" category, one in the "high-medium" stage, one in the "high" level, and one in "open water."

For the PMI group, the following breakdown was observed: one in "freshwater," six in the "low" level, three in the "low-medium" range, five in the "medium" category, one in the "high" level, and one in "open water."

Biological Profile: Age, Sex, and Stature

For the purposes of this study, only the age, sex, and stature of an individual was recorded and of interest. Given the possibility of differences in the rate of decay resulting from differences in body mass, body fat percentage, and height, these particular aspects of the biological profile were collected. Ancestry was not of interest given the fact that no logical link could be made between it and variations in the decomposition process.

Lastly, weight was not evaluated due to practical reasons. In cases where bodies had progressed to the "bloat" stage and beyond, measurements of weight were very unreliable. As decomposition progresses, fats melt, tissue is consumed and scattered, organs liquefy, and fluids are purged. Any measurements of weight passed the "fresh" stage of decomposition are thus meaningless, unless one is comparing pre-death weight to the percentage of weight loss upon recovery. When this consideration is coupled with the fact that investigators did not retroactively confirm the weight of individuals once they were identified, collection of body weight numbers were of no value, not to mention unreliable. Therefore, it was excluded from analysis. However, it is hoped that by recording information pertaining to age, sex, and height, some of the potential effects of body weight, mass, and fat percentage may be tied to and reflected in the percent of variation in estimating time since death explained by these aforementioned factors.

In regards to quantification, male and female groups were transformed using a binary code, with males assigned a score of one and females a score of two. In order to take the same approach to quantifying age and stature, an arbitrary distinction was chosen to divide the samples into two groups, as no "common sense" or logical divide was readily apparent. The cut-off for grouping age was above and below 50 years of age. In regards to stature, the distinction was above and below six feet tall.

In terms of the biological profile, the accumulated degree day group demonstrated a mean age at death of 51.6 years old, with a standard deviation of 18.6 years. The PMI day group showed an average of 53 years of age, with a standard deviation of 18.7 years. Throughout both data groups, the youngest age recorded was 16 and the oldest was 93. As stated above, no children below the age of 16 were included in the dataset so that differences in decomposition resulting from body size would be minimized.

For both groups, heights range from 58 inches to 74 inches tall. The average height also came in at a mean of 68 inches, or five feet, eight inches in height.

Although not incorporated into the analysis, ancestry was recorded for record keeping purposes. In total, the overwhelmingly majority of cases in both datasets consisted of individuals of European descent, accounting for nearly 75% of the cases. The next closest group was composed of African-Americans, making up almost a quarter of the dataset. The remaining three cases included two individuals of Asian descent and one of Hispanic origin.

As for sex, the majority of individuals in both groups were male, totaling 59 in the ADD set and 52 in the PMI group.

The Study Sample

After all the criteria were met and relevant data regarding variables were extracted, a total of 85 cases in various stages of decomposition were selected for the dataset (see Tables 9 through 16), with dates of recovery ranging from the year 2000 to 2013. Based on outlier removal, 80 of those cases were used for the creation of an accumulated degree day model, while 74 of those cases were suitable to a model evaluating the utility of post-mortem interval days for estimating time since death (the removal of outliers was discussed above). As has been mentioned throughout, this particular approach was taken so as to be able to evaluate which model explains more of the variation in decomposition. From there, a time since death equation can be developed utilizing the best model for the area. Of those cases in the accumulated degree day dataset, remains found indoors were the most common, equaling 37 cases. Bodies found in aquatic contexts totaled 23, while those found outdoors in non-aquatic circumstances accounted for 20 cases. In regards to the post-mortem interval day group, 39 cases were located indoors, 17 were deposited in aquatic circumstances, and 18 were found outdoors in non-aquatic environments.

Additionally, all cases were positively or presumptively identified. Identification was achieved through various means including DNA analysis, fingerprint matches, odontological comparison, and direct identification by family members. This latter identification method included visual observation, identification of unique scars, marks, and tattoos, and association with circumstantial evidence.

Furthermore, all cases were essentially complete, save for some missing bones due to disarticulation and scattering by scavengers or water transport. No cases were included which showed the loss of body parts or skeletal elements resulting from dismemberment or similar human-caused damage. Given the difficulties surrounding the modeling of burned, saponified, and buried remains in regards to decomposition, coupled with their low sample size, none of these types of cases were used in the study.

Statistical Analysis

The main crux of the quantitative component of this dissertation research revolves around the development of a regression equation by which to estimate time since death. As mentioned above, one of the most important considerations under evaluation is the specific role of accumulated degree days versus post-mortem interval days in explaining the largest proportion of variation in decomposition. Additionally, by incorporating data regarding the environmental and scene-specific variables described above, this research also seeks to determine which factors play a significant enough role in the decomposition process to warrant inclusion in the regression equation. Moreover, based on an evaluation of the proportion of variation in decomposition explained by a model incorporating all cases, versus a stratified model divided into non-water outdoor, indoor, and aquatic cases, it is hoped that insights can be gained regarding whether or not an over-arching general equation for estimating time since death, applicable to all contexts, is warranted, or instead, if equations derived for particular depositional contexts are better suited for such purposes. By stratifying analysis, one can also hope to determine if additional, unaccounted for factors are at play, driving down the proportion of variation explained by a model. Furthermore, by evaluating all of these aforementioned considerations, total body score may be demonstrated as a critical component of accurate, valid, and reliable time since death equations. Lastly, the single most important evaluation to consider revolves around whether or not the general time since death formula developed by Megyesi et al. (2005) is best suited to the Delaware River Valley region, or instead, if a region-specific equation is needed. Thus, in order to do so, several regression analyses utilizing SAS 9.3 were conducted.

Linear Regression Analysis: Total Body Score versus ADD or PMI

The first analytical technique utilized in this study employed the use of a linear regression analysis aimed at determining whether accumulated degree days or post-mortem interval days are more effective at modeling decomposition and the variation inherent in it. In order to do so, a linear regression analysis was run comparing the statistical significance of a model plotting total body score versus accumulated degree days, while the other plotted total body score versus post-mortem interval days. In both models, total body scores from aquatic cases were weighted in order to conform to the 3-42 point scale of the non-water outdoor and indoor TBS system. By doing so, the inclusion of cases with different total body scoring systems into the same model could be made easier. Given the interest in determining whether ADD or PMI explains the largest proportion of variation in decomposition in this particular analysis, total body score is the dependent variable to be predicted, while either ADD or PMI is the independent variable assessed.

A typical linear regression analysis seeks to develop an equation which attempts to minimize the distance between a "line of best fit" and observed values. A standard least-squares linear regression attempts to reduce the sum of the square of residuals, measured as the difference between observed and fitted values. However, given the lack of a linear relationship in either plot in this study, a standard least-squares linear regression was not appropriate, instead requiring the transformation of variables. In order to straighten the curve, and allow for a more direct least-squares linear regression (as well as the calculation of standard error and confidence intervals), it was observed that log-transforming both ADD and PMI, while leaving TBS untransformed, produces the most effective linear regression. The linear regression equation took the following form:

$$\mathrm{Log}_{10}(y) = Bx + \text{constant } (+ \text{ error})$$

In this particular case, B is the slope of the regression line, y is ADD or PMI, and x is TBS. The "constant" is a figure to be statistically derived from the analysis, added on following the multiplication of the slope and total body score. The "error" represents the standard error which can be added on to determine the error range below and above the figure produced by the equation.

Therefore, utilizing this transformation, a regression analysis was conducted in order to produce a regression equation for each model and determine which explains a larger proportion of the variation in decomposition, as represented by the coefficient of determination, R^2. This particular coefficient is a measure of how well or how close the observed data points are to a regression line best fitted to the dataset. The closer one gets to a value of one, the more variability the model explains and the better it fits the data.

Additionally, in order to meet the assumptions necessary for linear regression analysis, while considering the fact that the coefficient of determination cannot determine bias in the dataset, the normality, homogeneity of variance, and probability distributions of residuals were evaluated. An analysis of variance (ANOVA) test was also run in order to determine the significance of both regression models. Lastly, as a formality, parameter estimation was conducted to determine the standard error associated with total body score and demonstrate its statistical significance as a variable in both models.

Multivariate Regression Analysis: Determining the Significance of Additional Covariates for Estimating Time Since Death

As stated above, one of the goals of this dissertation research study was the determination of variables which not only play a role in influencing the rate of decay, but also the identification of those which produce enough of a statistically significant effect to warrant inclusion in a regression equation aimed at estimating time since death. In order to do so, separate multivariate regression analyses were run incorporating either accumulated degree days or post-mortem interval days as the dependent variable, and all of the variables mentioned above, including weighted total body score, as the independent variables. The goal was to identify the model which produces the highest adjusted R^2 value utilizing a stepwise selection, and thus, explains the largest proportion of variation in estimates of time since death. As always, those variables identified in the stepwise selection were assessed for their statistical significance or p values, and parameter estimates, including the calculation of the standard error for the appropriate variables, were generated.

This particular analysis was conducted for two main reasons. The first revolves around the ability of the stepwise selection to choose the variables which improve the model the most based on the adjusted R^2 values of each variable. The second deals with the nature of adjusted R^2 values in and of themselves. Unlike R^2, adjusted R^2 seeks to take into account the ability of R^2 values to increase as a result of the addition of extra variables. If one were to fill a model with variable after variable, R^2 values would invariably approach one. However, the inclusion of a plethora of variables would not actually be explaining anything, instead randomly raising the R^2 value due to their presence. Therefore, adjusted R^2 was developed to adjust for the number of explanatory variables included in a model. Thus, unlike R^2, adjusted R^2 increases only when a new variable is introduced that actually improves R^2 more than would be expected by chance alone.

Stratified Analysis: Linear Regression and Multivariate Regression Analyses of Specific Depositional Contexts

A stratified analysis of the three depositional contexts incorporated into this study was conducted for a number of reasons. The first reason was to demonstrate whether accumulated degree days or post-mortem interval days is more effective at explaining a larger proportion of the variation in decomposition in each depositional context, supporting or refuting the results demonstrated in the analysis conducted on the entire dataset. Secondly, a stratified analysis was conducted to also assess if particular variables in those contexts demonstrate a statistically significant effect on improving the coefficient of determination in the each stratified model. This particular method was employed to determine which variables play the largest role in explaining the variation observed in estimating time since death. Lastly, however, it was also important to determine if a particular depositional context demonstrates unusually low R^2 values, indicating the potential effects of as-yet-unknown variables on the decomposition process in such environments.

Therefore, in order to address these points, the same analyses conducted above were applied, except they used smaller subsets of the larger dataset. In regards to the first and third point mentioned, a linear regression analysis was run for each depositional context of interest to this study: non-water outdoor, indoor, and aquatic cases. An additional analysis was also run for the combination of non-water outdoor and indoor cases, given their hypothesized similarities in regards to decomposition, as well as their shared differences in comparison to aquatic cases and any regression models derived from them. Moreover, this particular approach was also taken by Megyesi et al. (2005). By replicating this specific methodology, comparisons between the model derived in this study and that of Megyesi et al. (2005) were made easier.

Moving on, the statistical significance of models for each context plotting total body score versus accumulated degree days and total body score versus post-mortem interval days, were evaluated. Based on the R^2 values of each model, decisions could be made regarding whether or not accumulated degree days or post-mortem interval days explain a larger proportion of the variation in decomposition per depositional context. The linear regression equations resulting from these analyses took the same form as that described above:

$$\mathrm{Log}_{10}(y) = Bx + \text{constant } (+ \text{ error})$$

In this way, assessments could be made regarding the usefulness of accumulated degree days versus post-mortem interval days in explaining the largest proportion of variation in decomposition, while highlighting any particular depositional contexts which demonstrate very low R^2 values. In turn, this could bring to light the existence of unknown variables altering the decay process in that particular context, and the need to develop new modelling techniques in that specific depositional environment.

Moreover, in order to meet the assumptions of linear regression analysis, plots of the residuals were generated in order to assess the normality, homogeneity of variance, and probability distributions of the difference between the observed and predicted data points. Analysis of variance was assessed to demonstrate the statistical significance of each model.

Finally, in regards to the assessment of variables playing a statistically significant role in each depositional context, the same stepwise selection method, utilizing the highest adjusted R^2 values, was employed for both the accumulated degree day and post-mortem interval day groups. The p values for each variable demonstrating the highest adjusted R^2 figures were assessed for statistical significance. Parameter estimates were also generated for each. By utilizing the stepwise selection method, the model could be fine-tuned by bringing to the forefront those variables which explain the largest proportion of variation, and improve the model the most.

Rate of Decay: Influence of Variables

In addition to evaluating those variables which account for the largest proportion of variation in estimates of time since death, this study also sought to understand the effects of various variables on the rate of decay. Obviously, based on the particular depositional context faced by each individual case, different variables will play a role. For example, soil pH cannot be evaluated in aquatic cases. In total, all of the variables discussed above were evaluated in this analysis.

For those cases where the evaluation of the particular variable in question was applicable, the total body score was divided by the accumulated degree day total in each individual case, with the mean of that calculation representing the overall effect of the variable on the rate of decay. The same method was employed utilizing the post-mortem interval day group, obviously substituting ADD for PMI in that analysis. From there, the means for each variable were compared to those of their counterparts. For example, the data from clean houses was evaluated against those from dirty houses, exposed remains were compared against shaded remains, trauma cases were assessed against non-traumatic cases, and so forth. In order to evaluate each comparison, it was determined if a statistically significant difference existed between both variables. Nearly significant differences were also recorded, in order to identify those variables which may prove significant when evaluated in larger sample sizes. As a result, the study could identify whether the presence or absence of specific variables plays a role in accelerating or decelerating the rate of decay.

Along the same vein, these methods were also employed in regards to non-water outdoor and indoor cases together, excluding aquatic cases. This particular decision was made given the fact that aquatic cases operate on a different TBS scale. Also, variables such as salinity levels are not applicable to non-water outdoor and indoor cases. Lastly, given the fact that some variables analyzed, such as insect activity, were not observed in great numbers in aquatic cases, they were not included in the analysis to avoid distorting the results.

Additionally, continuous plots were developed demonstrating the data points of each variable plotted against logADD. In this way, the plots could be evaluated in order to determine if a relationship is apparent or if any noticeable trends between ADD and a particular variable can be detected. If this was found to be the case, it could also highlight the need for further evaluation of that particular variable.

Lastly, it should be noted that these methods were applied incorporating the cases from all depositional contexts in both the accumulated degree day and post-mortem interval day groups. A separate analysis, including only the combination of non-water outdoor and indoor cases from the accumulated degree day dataset, was also conducted; keeping in mind the similarities both depositional contexts were observed to share in regards to decomposition and the proportion of variation explained by accumulated degree days, to be discussed in the next chapter.

Rate of Decay: Differences between Depositional Contexts

Given the difficulties involved in assessing the rate of decay between depositional contexts utilizing the methods described in the previous section, coupled with the drawbacks of such analyses using data extracted from retroactive studies, another technique was devised to assess the time required to produce specific total body score intervals. In order to do so, the formulas derived for the outdoor and indoor depositional contexts were compared to each other. Each equation was used to predict accumulated degree days in their respective contexts, utilizing the same total body scores in each comparison. Estimates were derived for each total body score from three to 42 using the non-water outdoor and indoor formulas. The aquatic equation was not incorporated into the comparison given the different total body score scale employed in the assessment of decomposition in water contexts, complicating any comparisons with the equations derived in the remaining contexts.

In total, by assessing the predicted ADD required to produce each total body score, one can theoretically evaluate which contexts are the slowest or fastest at reaching each one of those phases of decomposition. In turn, this could provide insights into the rate of decay in each depositional context.

Logarithmic versus Square Transformation: Comparison to Megyesi et al.'s (2005) Model

Penultimately, given the fact that Megyesi et al.'s (2005) study laid the foundation for the quantitative analysis of decomposition utilizing accumulated degree days in forensic anthropology, the model derived from that particular analysis was compared to the model derived in this dissertation research study. This particular comparison is a crucial aspect of the evaluation of whether or not universal time since death estimation equations, applied across various regions, are effective, or instead, if region-specific equations are necessary. It must be kept in mind that not only is the Megyesi et al. (2005) data different, utilizing cases from 19 different states ranging from Washington to Florida, but the total body score system was developed based on the particular decompositional changes and patterns observed in their specific dataset. Given these differences, Megyesi et al. (2005) developed a model best suited to explain the variation in decomposition observed in their dataset and estimate time since death based on the particular decompositional patterns observed in the cases derived from their region of interest. As a result, Megyesi et al. (2005: 6) state that their linear regression analysis required not only the log transformation of both ADD and PMI, but also the squaring of TBS "to produce the most effective linear regression." This transformation is different from the simple logarithmic transformation utilized in this study.

Therefore, in order to compare the equations derived from both studies, the overall model and the non-water outdoor and indoor model derived in this study were both reformulated to mimic the model developed in the Megyesi et al. (2005) study. Given the fact that the Megyesi et al. (2005) study incorporated only non-water outdoor and indoor cases, it was felt that a comparison should be made using both the subset and overall model developed for the Delaware River Valley. From there, the data points extracted from Delaware were applied to these "copycat" models. Essentially, the data from this study was incorporated into their model and the coefficient of determination, R^2, was compared to determine which model explains a larger proportion of the variation in decomposition, with comparisons utilizing both the overall model and the non-water outdoor and indoor model. In this way, one can evaluate whether or not the models derived in this study are better suited to explain decomposition and estimate time since death for cases found in the Delaware River Valley region compared to the Megyesi et al. (2005) study, supporting or refuting assertions regarding the necessity for region-specific standards.

Predicted versus Observed ADD Value Comparison: Megyesi et al. (2005) Model versus Delaware River Valley Overall Model and Outdoor/Indoor Model

Lastly, in order to drive home the points made in the previous section, the average, average differential, and absolute value of the average differential of predicted accumulated degree days were compared to actual, observed accumulated degree days calculated using both the Megyesi et al. (2005) and the Delaware River Valley overall model. This particular comparison was made utilizing all of the cases in the dataset, including all depositional contexts. A second comparison was made, structured in exactly the same manner, except the models used were the Megyesi et al. (2005) model and the Delaware River Valley non-water outdoor and indoor model. The reason for this decision is directly related to the fact that the Megyesi et al. (2005) model only incorporates non-water outdoor and indoor cases. Therefore, a direct comparison of those specific case types was warranted.

In order to do so, all cases in the dataset were scored utilizing the Delaware River Valley total body score system. Additionally, each of these cases was also scored utilizing the TBS system devised by Megyesi et al. (2005). Given the different total body score totals between the non-water outdoor and indoor TBS system, and that of the aquatic TBS standards, a weighted conversion needed to be developed. In order to do so, total body scores from aquatic cases were weighted according to the 1-42 point non-water outdoor and indoor TBS scale and inputted into the Delaware River Valley model in order to determine predicted accumulated degree days. In regards to scoring these cases for the Megyesi et al. (2005) model, the weighted aquatic cases were converted once more to conform to the 1-35 point TBS scale developed in the Megyesi et al. (2005). From there, the accumulated degree days were predicted in each case for both models. Using those calculations, the average predicted ADD was determined and compared to the average observed ADD. Furthermore, the average differential and average absolute value differential between the predicted and observed values were calculated and compared between models. A simple two-sample t-test of unequal variances was run in Excel in order to determine the statistical significance of each comparison.

Moreover, the non-water outdoor and indoor case types were evaluated as well. This particular step was taken so as to evaluate the Megyesi et al. (2005) model in its intended format versus the Delaware River Valley non-water outdoor and indoor model. Once again, a total body score was developed for each case utilizing the total body score system devised in each study. From there, the total body scores were inputted into each study’s respective ADD prediction formula and a set of predicted ADDs were developed for each case. The remaining steps taken are identical to those described above.

In total, the main idea behind these analytical comparisons seeks to determine which model more accurately predicts accumulated degree days by comparing predicted versus observed values. In all, this comparison may serve to further support arguments for or against the development of region-specific standards.

Chapter Nine: Results

Development of a Total Body Score System for Assessing Decomposition in the Delaware River Valley

In order to quantify the decompositional changes which occurred in each individual case and assign total body scores which accurately reflected the joint effects of various variables, including temperature, on the decay process, it was crucial to identify the particular decompositional patterns observed in the region. Furthermore, by conducting an analysis of this type, assessments could be made regarding whether or not a distinct progression to decomposition occurs in the Delaware River Valley. This particular evaluation serves to not only justify the development of total body score descriptions representative of the decay process in the area, but it also plays a pivotal role in the justification of region-specific standards.

Fortunately, a pattern began to emerge concerning the decompositional changes which occur over time, facilitating the creation of a set of standards particular to non-water outdoor and indoor, as well as aquatic depositional contexts. The changes observed between corpses exposed to non-water outdoor and indoor contexts overlapped tremendously; therefore, justifying the development of a single set of total body scores applicable to both depositional environments. In fact, this particular observation was also made by Megyesi et al. (2005) and demonstrated in the application of the total body score system developed in that study to cases in both contexts. In regards to the decompositional process in aquatic environments, the specific decompositional pattern observed warranted the development of a total body score particular to cases exposed to aquatic contexts. Additionally, general stages of decomposition were observed, corresponding to fresh, early, moderate, advanced, and skeletonized phases. Within each stage, the typical changes which occurred were identified and broken down into sub-stages.

What is crucial to note however, is that these observed decompositional changes and patterns did not overlap with those identified in either Megyesi et al. (2005) or Heaton et al. (2010). Rather, a distinct progression to decomposition was observed in cases derived from Delaware. Given the recognition that the use of inappropriate decompositional descriptions in an area, and thus inaccurate total body scores, can be disastrous to quantitative estimates of time since death, the development of a total body score system representative of the changes observed to occur in the Delaware River Valley Region became ever more important. As a consequence of this critical discovery, a region-specific total body score system was developed.

In regards to the particular pattern of decomposition observed, tables 23 through 28 represent the total body score system developed for each of the three main areas of the body, in both non-water and aquatic contexts. Given the identification of many more sub-stages of decomposition on land, the non-water outdoor and indoor standards demonstrate more categories. A particular discussion of the specific decompositional changes and patterns observed in each depositional context can be found in the next chapter.

In total, a distinct progression to decomposition was observed in cases derived from the Delaware River Valley, justifying the development of a set of region-specific total body score descriptions representative of those differences.

Accumulated Degree Days versus Post-Mortem Interval Days: Explaining the Largest Proportion of Variation in Decomposition

One of the most crucial factors to be evaluated by this study involved the assessment of the utility of accumulated degree days versus post-mortem interval days for explaining the largest proportion of variation in decomposition. In order to do so, a linear regression analysis, incorporating the entire dataset, was run. When the coefficient of determination was compared between both models, it was observed that accumulated degree days demonstrated a larger R^2 value, equaling 0.7852 (see Figure 15), which is in comparison to a value of 0.6434 when utilizing post-mortem interval days (see Figure 16). Thus, the accumulated degree day model clearly explained more of the variation in decomposition compared to the use of post-mortem interval days. Given this particular discovery, it obviously warrants the use of ADD over PMI in the development of a regression equation by which to estimate time since death; a step which was taken throughout the remainder of the study.

In regards to the analysis of variance, the accumulated degree day model proved to be extremely statistically significant, with a *p*-value of less than 0.0001, or well below the threshold of 0.05 (see Table 29). This particular statistic signifies that the differences observed are very unlikely to be the result of random sampling.

Furthermore, in order to evaluate the validity of the *p*-value in the *t*-test and ensure that the assumption of the normal distribution of residuals in the linear regression analysis was met, the distribution of residuals was plotted and observed to be normally distributed. The assumption of the homogeneity of variance of the residuals was also met, only demonstrating an unproblematic slight narrowing of points from left to right.

The probability distribution of residuals was also within the normal range. Therefore, based on these results, the assumptions of linear regression analysis for the accumulated degree day model were satisfied (see Figure 17), validating the model.

Lastly, in regards to the parameter estimates, total body score was observed to be an extremely statistically significant variable, with a *p*-value less than 0.0001 (see Table 29). The parameter estimate for total body score was 0.05703 and the standard error was calculated to be 0.00338. In regards to the intercept identified in the linear regression, the parameter estimate was determined to be 1.52523 and the standard error was calculated as 0.05812. The intercept was also deemed extremely statistically significant. It should be noted that the post-mortem interval day model was also statistically significant itself; however, as mentioned above, the use of accumulated degree days is more effective at explaining more of the variation in decomposition, and thus, was favored throughout the study. Total body score proved to be a statistically significant variable in both models as well.

As a result of these efforts, the linear regression equation developed utilizing accumulated degree days and total body score is as follows:

$$\text{LogADD} = 1.52523 + 0.05703(\text{TBS}) + [\text{error}]$$

Based on this regression equation, in order to estimate time since death, accumulated degree days must be calculated. However, in order to bolster the statistical inferences which can be made and provide statistical backing in support of estimates derived from this equation, the standard error and a 95% confidence interval must first be applied. In order to calculate the confidence interval, the following equation should be expanded upon:

$$\text{predicted value +/- } t_{crit} \text{ * standard error}$$

The standard error is calculated as follows:

$$\text{standard error of the estimate*}\sqrt{}1/n + (\text{actual X} - \text{predicted X})^2/SS_x$$

The standard error of the estimate is calculated as follows:

$$\sqrt{}\ \sum(\text{actual Y} - \text{predicted Y})^2 \ / \ N\text{-}2$$

In order to calculate the prediction interval, the base equation remains the same. However, the standard error must be calculated as follows:

$$\text{standard error of the estimate*}\sqrt{}1 + 1/n + (\text{actual X} - \text{predicted X})^2/SS_x$$

It is important to explain that by utilizing this level of confidence, one is stating that 95% of the time, the true population parameter (i.e. the actual ADD total) will be within the range provided. The confidence interval reveals how well the mean was determined. Prediction intervals on the otherhand, must not only taken into account the uncertainty of knowing the value of the population mean, but also the distribution of values, or data scatter. The prediction interval lays out where the next data point can be expected to be sampled. Therefore, it is always larger than the confidence interval.

Additionally, the standard error reflects the statistical accuracy of the estimate to be derived, likened to the standard deviation of a theoretical distribution of such estimates.

Thus, in practice, one simply needs to determine the total body score, plug the value into the equation to determine the confidence and prediction interval limits, and determine the accumulated degree day range. Should one simply want to calculate the single predicted ADD estimate, the original equation, without the standard error or confidence interval, should be used.

Clearly, based on the nature of statistical calculations, the ranges will increase in size the further along in the decomposition process one goes. Thus, the narrowest time since death estimates will be found in the earlier stages of decomposition, expanding with higher total body scores.

In total, accumulated degree days accounts for more of the observed variation in human decomposition when compared to post-mortem interval days. Regardless of the depositional context, accumulated degree days should serve as the variable to be predicted in order to most reliably and accurately estimate time since death. Given the development of a regression equation by which to estimate time since death with known standard errors and within a 95% confidence interval, the requirements set forth in *Daubert* (1993), *Kumho* (1999), the Federal Rules of Evidence rule 702 (2000), and the National Academy of Sciences' report (2009) have been met.

Most importantly, an overall time since death equation, incorporating the area-specific effects of variables on the decomposition process, has also been developed, demonstrating the potential to derive an accurate, valid, and reliable region-specific time since death estimation equation.

Modelling Decomposition and Estimating Time since Death in Specific Depositional Contexts

In order to take the evaluation of accumulated degree days versus post-mortem interval days a step further and develop regression equations particular to specific depositional contexts, as well as identify which contexts may be impacted by as-yet-unknown variables, a stratified analysis was conducted. The analysis consisted of the creation of subsets of data based on depositional context, including indoor, outdoor, and aquatic cases. Linear regression analyses were run for the cases in each subset, utilizing either ADD or PMI. Based on the results of the analysis, the accumulated degree day model exhibited a larger R^2 value in each and every subset, explaining a larger proportion of the variation in decomposition throughout.

In regards to the indoor cases, the ADD model demonstrated a coefficient of determination of 0.6576 (see Figure 18), versus 0.6176 in the PMI group (see Figure 19). The non-water outdoor cases were particularly intriguing, exhibiting huge R^2 values of 0.8965 in the ADD group (see Figure 20), versus 0.8568 in the PMI model (see Figure 21). The explanatory value of the non-water outdoor model is impressively high.

Moreover, the results of the linear regression analysis conducted on the aquatic cases were arguably among the most illuminating, not only highlighting the fact that the accumulated degree day model fared better with an R^2 of 0.5264 (see Figure 22), versus 0.0761 in the PMI group (see Figure 23), but it also brought to light the potential existence of confounding factors in the estimation of time since death in water contexts, especially when using post-mortem interval days as a measure of time. In fact, of all the models tested, only the model including post-mortem interval days and aquatic cases was demonstrated to not be statistically significant, instead showing a *p*-value in the analysis of variance of 0.2839. All other models derived from the remaining subsets showed statistically significant *p*-values below 0.0001. The significance of these discoveries will be discussed in more detail in the next chapter.

Lastly, given the observed decompositional similarities among cases found in non-water outdoor and indoor contexts, the data from both subsets were combined in the accumulated degree day model. When a linear regression analysis was run, it was discovered that together, they demonstrate an R^2 value of 0.8205 (see Figure 24). This particular find is of importance not only due to the high proportion of variation explained, but also due to the fact that the R^2 value is higher than the overall model including all cases. This not only reveals the ability to utilize the time since death equation on both non-water outdoor and indoor cases, but also the difficulty in modeling aquatic cases, which appears to have dragged down the R^2 value in the overall model. In total, the linear regression equation derived from the analysis is as follows:

$$\text{LogADD} = 1.5466 + 0.0557(\text{TBS}) + (\text{error})$$

Lastly, as will be discussed in more detail below, having a non-water outdoor and indoor model with high explanatory value is important to facilitating comparisons between the Delaware River Valley model derived in this region and that of the Megyesi et al. (2005) model.

Statistically-Significant Covariates for Estimating Time since Death

The next step in the assessment of decomposition and the development of a time since death regression equation involved the evaluation of variables posited to impact the rate of decay. In order to do so, a stepwise selection method was employed, selecting those variables determined to have the highest adjusted R^2 values in each model. For the sake of consistency, this particular determination was made utilizing both the accumulated degree day and post-mortem interval day models.

In the overall accumulated degree day model, four variables were selected based on their adjusted R^2 values. These variables included type of depositional context, clothing, total body score, and body position, with the latter encompassing supine, prone, left leaning, right leaning, seated, and hanging bodies. However, it was determined that only total body score proved to demonstrate a statistically significant effect, with a *p*-value once again less than 0.0001 (see Table 30).

In regards to the post-mortem interval day model, six variables were selected based on their adjusted R^2 values. These variables included precipitation, insect activity, age, sex, height, and total body score. This time, precipitation, in addition to total body score, demonstrated a statistically significant relationship, with *p*-values less than 0.0001 (see Table 31). Although the ADD model is favored over the PMI model, it is of particular importance that total body score has been identified as producing a statistically significant effect in both. As will be discussed in the next chapter, developing an accurate total body score system representative of the decompositional changes which take place in an area, appears to be one of the most crucial factors involved in the development of a valid, reliable, and accurate time since death estimation model.

Additionally, in order to attempt to identify even more trends in the data, the various subsets investigated in this study were probed utilizing a stepwise selection method to determine if statistically significant covariates could be discovered in cases exposed to the various depositional contexts investigated here. Unfortunately, given the subdivided nature of these stratified analyses, sample sizes were generally too low to identify any meaningful trends. Variables, which may typically have demonstrated a statistically significant effect, may not have been selected given the low sample sizes at this subdivided level of analysis.

However, what is of importance to note is that once again, it appears as if total body score plays the most important role in all models. Specifically, the indoor subset, for both the ADD and PMI models, identified total body score as demonstrating a statistically significant effect (see Table 32). What's more, when examining the continuous plot of logADD versus total body score, it is clear that the same relationship is shared across all depositional contexts (see Figure 25). In fact, these exact results are supported by the finds discussed in Bachmann and Simmons (2010), serving to further substantiate the trends observed in this study.

Even more telling is the result of the stepwise selection method for non-water outdoor cases utilizing the PMI model (see Table 33). When this particular analysis was run, the following message was produced: "Selection stopped because all candidate effects for entry are linearly dependent on effects in the model." Based on the statistical observations made thus far, as well as the understanding that that the joint effects of all variables are reflected in the decompositional changes noted in the total body score, the identification of this linear dependence points straight at the importance of the total body score for producing accurate estimates of time since death.

Examining Relationships: Continuous Plots of logADD versus Environmental, Scene-Specific, and Depositional Variables

In order to assess any potential observable trends or relationships between logADD and the various number of factors examined in this study, the continuous plots of logADD versus each variable were analyzed. The results brought to light some points to consider. It should be noted however, that the analysis of continuous plots was not employed to detect concrete correlations or statistically significant relationships; instead, they are used to identify additional variables which may warrant further investigation in the future when a larger sample size can be developed to draw out their true effects.

First off, as mentioned above, when logADD was plotted versus the total body score, the same linear relationship was observed across all case types (see Figure 25). This serves to further cement the importance of the total body score to estimates of time since death and the development of models from which to do so.

Next, it appears that when precipitation levels increase, logADD values increase as well (see Figure 26). As would be expected, this particular trend was noticed more so in non-water cases. Given the known relationship between temperature, humidity, aridity, and precipitation, this particular relationship may be a function of the increased moisture levels inherent to higher temperatures in a temperate climate such as that experienced in the Delaware River Valley. Unfortunately, a larger sample size would be needed to extract more meaningful conclusions from this relationship. However, although the post-mortem interval day overall model, in which precipitation was observed to display a statistically significant effect, is not particularly effective at explaining a large proportion of the variation in decomposition, this variable may be of interest to future studies when considered alongside the results of the continuous plot.

Moreover, the presence, absence, and degree of insect activity may demonstrate a relationship with logADD (see Figure 27). If the cases demonstrating no evidence of insect activity are removed from consideration, a trend is somewhat apparent in the continuous plot, with the increase in insect activity appearing to coincide in part with an increase in the logADD. However, over time, it also appears as if the relationship switches, potentially coinciding with the end of insect activity. This particular observation not only highlights an important point in regards to the presence of insects on a corpse, but also regarding the use of retroactive data collection, which will be discussed in the next chapter. Nonetheless, regardless of the potential relationship, more cases would be needed to provide more concrete conclusions.

In regards to the remaining variables, either the relationships demonstrated no distinguishable pattern, or the binary nature of the distribution was not well-suited to an examination of trends. In particular, no relationship was observed between logADD and age, height, or weight (see Figures 28, 29, and 30). In terms of the binary variables, such as biological sex, evidence of trauma versus no evidence of trauma, scavenging activity versus no scavenging activity, and so forth, many more cases would be needed to even begin identifying recognizable and significant relationships. Given the limited number of cases exhibiting information pertaining to these specific variables, future studies must seek to expand sample sizes with these particular factors in mind.

Overall however, based on the totality of the results described in this section, the relationship shown in regards to total body score is very encouraging. The effects played by precipitation and insect activity may be drawn out by future studies in which larger sample sizes increase the statistical inferences which may potentially be derived from the dataset.

Environmental and Scene-Specific Variables Affecting the Rate of Decay

In order to attempt to identify clear relationships between the various factors assessed in this study and the rate of decay, the mean rate of decay per variable was analyzed and compared to its counterpart. For example, the mean rate of decay was compared between dirty and clean houses, shaded versus exposed remains, traumatic versus non-traumatic cases, and so forth. This method was applied to all cases in the dataset, as well as the non-water outdoor and indoor samples combined. Given the retroactive approach taken toward data accumulation, which comes with its own drawbacks to be discussed later, not much information was expected to be derived from this analysis, especially given the results of the stepwise selection mentioned above. Additionally, given the fact that many of the variables assessed are applicable to only one or two of the depositional contexts incorporated into the study, the sample sizes for each variable were not as robust. Therefore, the results from this section were not expected to provide any major revelations, but instead were intended to serve as support for any trends observed, if any were detected.

In fact, very few statistically significant environmental and scene-specific factors were identified, regardless of the depositional contexts included. Of those variables which did demonstrate a statistically significant effect, many results were counter-intuitive and "inverted." For example, in regards to no scavenging activity versus scavenging activity, it was observed that in cases where no evidence of scavenging activity was observed, the mean rate of decay was roughly two times higher than in those cases where evidence of scavenging was seen, reflected in the higher mean rate and statistically significant difference between both groups. The same relationship was observed in cases where no insect activity was observed versus cases where insects were present. Although these results appear counter-intuitive, they highlight a critical consideration in regards to cross-sectional studies and the timing and acquisition of data: retroactive studies cannot control when particular variables "enter" or appear into the study. In other words, critical differences in the TBS and ADD between cases in the varying depositional contexts have directly impacted the results, producing the inverted or counter-intuitive observations seen. This particular discussion is of great theoretical and methodological value and will be expanded upon in the following chapter.

Lastly, and most importantly, the results derived from this analysis serve to support the linear dependence statement referenced above, pointing to a much larger consideration. In studies evaluating the role played by variables in the decomposition process, the effects of said factors cannot be parceled apart, as they all contribute jointly to the decompositional changes represented in the total body score. These results are directly aligned with the findings of Bachmann and Simmons (2010), who claim that total body score alone is the most significant variable involved in estimating time since death.

Depositional Contexts and the Rate of Decay

In order to assess the ADD required to produce all possible total body score counts in the outdoor and indoor depositional contexts, and thus infer the rate of decomposition by type of environment, the respective formulas for these depositional contexts were utilized to predict accumulated degree days. The non-water outdoor and indoor equations were used to predict ADD for each total body score from three to 42.

Based on the results of this comparison, in the early post-mortem period, cases in indoor contexts required the lowest ADD total to produce the specified total body score, with outdoor cases taking the longest (see Table 34). Similar to the counter-intuitive results described above, these particular finds contrasted with the relationship proposed by Maples and Browning (1994), which stated that outdoor bodies decompose faster than bodies deposited in indoor contexts.

However, upon analysis of the entire set of results, it was observed that as the TBS approached the latter half of the early stage of decomposition, the trend reversed (see Table 34). In fact, from estimates predicted with total body scores of 12 and higher, outdoor cases were seen to require less and less accumulated degree days to produce each total body score, demonstrating a faster rate of decay compared to indoor cases. In total, the differences between the results of the indoor versus non-water outdoor formula were found to be statistically significant (see Table 35).

What's more, when the non-water outdoor and indoor subsets were combined, and the equation derived for both contexts was utilized, the same trend was observed. Although the combined model was slightly delayed, it still showed a faster decay rate when using total body scores passed the latter half of the early stage of decomposition, in comparison to indoor cases alone. In fact, the difference between the results of the non-water outdoor and indoor case formula, in comparison to those derived utilizing the indoor formula alone, was once again statistically different (see Table 36).

Although the reasons for these differences will be discussed in the following chapter, these results support the findings of Maples and Browning (1994), demonstrating outdoor cases to theoretically decompose at a faster rate than indoor cases. Additionally, these results continue to support the use of the combined non-water outdoor and indoor model, as a faster rate of decay was observed in comparison to the indoor subset.

Lastly, an additional, tangential discovery was made upon examination of these results. Across each and every formula utilized, the higher the total body score, the more spread out the predicted accumulated degree days became. In particular, this signals a larger error range the further one gets from the actual point of death. This find coincides with the inverted relationship between the preciseness of estimates of time since death and the length of time an individual has been deceased for.

Comparison of Time since Death Estimation Models: Megyesi et al. versus Delaware River Valley Model

The single most important analyses in this study involve the comparison of the models derived specifically for the Delaware River Valley and that developed by Megyesi et al. (2005). Given the need to evaluate the necessity of region-specific decomposition standards and total body score descriptions versus a more general, universal decomposition model, this specific comparison of models is crucial to such evaluations.

In order to do so, the model developed by Megyesi et al. (2005) was evaluated in conjunction with the data extracted from the Delaware River Valley area. This involved applying Megyesi et al.'s (2005) logADD versus TBS squared regression model to all of the data points in the overall accumulated degree day group collected for this study. The result was an R^2 value of 0.7202 (see Figure 31). When these results are compared to the R^2 values derived from the overall ADD model developed here, the region-specific Delaware River Valley model fares better, with an R^2 of 0.7852 (see Figure 15). Analysis of variance indicates that both models are statistically significant ($p < 0.0001$).

In order to further drive home this point, the same analysis was conducted comparing PMI models. Utilizing the Megyesi et al. (2005) model on all of the data collected in the Delaware River Valley, an R^2 value of 0.5894 was achieved (see Figure 32). However, when this is compared to the PMI model developed in this study, an R^2 value of 0.6434 is observed (see Figure 16). Analysis of variance indicates that both models are statistically significant ($p < 0.0001$). Once again, the model derived specifically for the Delaware River Valley area, utilizing the specific total body score descriptions derived from the analysis of decompositional patterns and changes in corpses found in Delaware, proves to explain a greater proportion of variation in decomposition.

Moreover, it is important to note that in the Megyesi et al. (2005) study, both non-water outdoor and indoor cases were combined and evaluated jointly. Thus, the regression equation developed in the study did not take into account any aquatic cases. This particular step was taken to not only simplify the estimation of time since death across non-water cases, but it was also done with the understanding that outdoor and indoor cases do not differ significantly in regards to the decompositional changes and patterns observed. Therefore, in order to protect against concerns regarding the inclusion of cases from both aquatic and non-aquatic contexts in this study's general regression model, a regression model for non-water outdoor and indoor cases was specifically designed in this study. In fact, given the differences in the total body score system between aquatic and non-aquatic cases observed here, this subdivision may actually make more sense.

Regardless, the model developed by Megyesi et al. (2005) was once again applied to the accumulated degree day group in this study, except this time, only non-water outdoor and indoor cases were included in the analysis. The resulting R^2 value was 0.7596 (see Figure 33). When this figure was compared to the non-water outdoor and indoor regression equation and analysis developed in this study, once again, the R^2 value proved to be greater, equaling 0.8205 (see Figure 24).

Additionally, as was done with the general model, the PMI group was compared utilizing only non-water outdoor and indoor cases. In regards to the R^2 value using the

Megyesi et al. (2005) model, the figure equaled 0.6809 (see Figure 34); this is in comparison to the R^2 value of 0.7560 in the non-water outdoor and indoor model derived in the Delaware River Valley study (see Figure 35). Analysis of variance of all the models described indicates they are all statistically significant ($p < 0.0001$). Clearly, the results from both the ADD and PMI models speak for themselves.

Lastly, given the larger explanatory potential of the Delaware River Valley model, a final set of analyses were conducted in order to further emphasize the greater applicability and accuracy of the Delaware River Valley model to cases found in this area. In particular, the average predicted accumulated degree days, as well as the average differential and absolute value of the average differential of predicted accumulated degree days, were compared to actual accumulated degree days observed in each case, using both the Megyesi et al. (2005) and the Delaware River Valley overall models. In order to evaluate the effectiveness of the Megyesi et al. (2005) model and the non-water outdoor and indoor Delaware River Valley model at predicting accumulated degree days, a comparison was also made between predicted and observed values in these particular case types. As mentioned earlier, this decision was based on the fact that the Megyesi et al. (2005) study only utilized non-water outdoor and indoor cases. Thus, given the evaluation of like cases, a more direct comparison of models is possible.

In regards to the first comparison of observed versus predicted values utilizing all cases, the average observed ADD value equaled 470.892. This figure is in comparison to a mean ADD value of 528.899 in the overall Delaware River Valley model, and 535.215 in the Megyesi et al. (2005) model. The standard deviation of the predicted values using the Delaware River Valley formula, 865.640, was also closer to the actual standard deviation of 674.066, compared to 1131.718 in the Megyesi et al. (2005) model (see Table 37).

In terms of the average differential and average absolute value differential between observed and predicted ADD values, the Delaware River Valley equation demonstrated more accurate results, with means of 58.007 and 195.203, respectively (see Tables 38 and 39). The Megyesi et al. (2005) formula averaged a differential of 64.323 and an absolute value differential of 236.782. In total, although these differences were not statistically significant, it is believed that in a larger sample size, the differential would prove to be significant, as the statistical power increases. More importantly, these results support the finds detailed above in terms of R^2 value comparison. Overall, the general Delaware River Valley model proved more accurate at predicting accumulated degree days.

In regards to the comparison of observed versus predicted values utilizing only non-water outdoor and indoor cases, the Delaware River Valley non-water outdoor and indoor model proved to be even more accurate at predicting ADD than the general model, and most importantly, than the Megyesi et al. (2005) model. In terms of the average observed ADD values seen throughout these cases, the mean equaled 570.268. This figure is in comparison to a remarkably accurate mean predicted ADD value of 572.915 in the Delaware River Valley non-water outdoor and indoor model, and 669.791 in the Megyesi et al. (2005) model. The standard deviation of the predicted values using the Delaware River Valley formula, 941.907, was also closer to the actual standard deviation of 761.934, compared to 1316.002 in the Megyesi et al. (2005) model (see Table 40).

In terms of the average differential and average absolute value differential between observed and predicted ADD values, the Delaware River Valley non-water outdoor and indoor equation demonstrated remarkably accurate results, with a mean differential of only 2.647, and a mean absolute value differential of 199.912 (see Tables 41 and 42). The Megyesi et al. (2005) formula averaged a differential of 99.523 and an absolute value differential of 300.677. As stated above, none of these differences were demonstrated to be statistically significant given the sample size, but should the number of data points increase, it is believed these differences would demonstrate significant results.

In total, when applied to data derived from this region, across each and every comparison made between the Megyesi et al. (2005) model and the Delaware River Valley model, the Delaware River Valley equation fared better every single time, regardless of if comparisons were being made between the coefficient of determination or predicted versus observed values. Given these results, not only are region-specific standards warranted, but when applied to cases found in the Delaware River Valley, the time since death equation developed here will allow for more precise, accurate, valid, and reliable estimates of time since death.

Summary of Results

Based on the plethora of qualitative and quantitative analyses conducted, a number of important research results have been found. When these results are evaluated jointly, they reveal the creation of a time since death equation well-suited to assessing decomposition in the Delaware River Valley Region and validate the development of region-specific time since death equations.

As will be discussed in the following sections, total body score plays a critical role in developing a decomposition model from which to provide estimates of time since death. Given the fact that a distinct progression to decomposition has been detected in the Delaware River Valley, coupled with the fact that the joint effects of multiple variables are reflected in the decompositional changes noted in the total body score for each individual case, it quickly becomes apparent that accurate total body score descriptions will make up a fundamental aspect of the development of a decomposition model which accounts for the largest proportion of variation in the decay process. Its statistically significant effect across the models developed in this study further substantiates its central position and cements its importance as a key aspect of time since death equations.

With regard to the assessment of accumulated degree days versus post-mortem interval days, ADD dominates the comparisons, demonstrating a larger coefficient of determination in each and every model considered. Whether evaluating the overall model including all depositional contexts or each stratified subset, accumulated degree days explains a larger proportion of the variation in decomposition in all cases. Without a doubt, the incorporation of both time and temperature in the form of accumulated degree days is of more value in modeling decomposition and estimating time since death.

Along with the development of a time since death estimation equation applicable across all cases, stratified analyses also demonstrated impressive results. Both non-water outdoor and indoor contexts explain a great deal of the observed variation, especially when combined jointly into one model. However, the same cannot be said with regard to cases deposited in aquatic contexts. As a matter of fact, the low R^2 values seen, especially in the aquatic PMI model, signifies the existence of confounding variables which are either as-yet-unknown or relatively impossible to track. Although the overall model explains a large proportion of the variation, the similarities in decomposition shared between cases in non-water outdoor and indoor contexts and the high R^2 values seen in their joint model, coupled with the low coefficient of determination demonstrated in the subset containing only aquatic cases, suggests that the joint non-water outdoor and indoor model will be of potential use in the medico-legal community.

Besides the continued confirmation of the important role played by total body score, no other variables demonstrated a sustained statistically significant effect across decomposition models, regardless of the analytical level assessed. Although this particular discovery may appear to suggest that no additional variables were observed to play a role in the decay process, this is far from the case. Given the linear dependence identified in the non-water outdoor PMI model, an important statement can be drawn from that discovery: a variable exists in the dataset which incorporates the joint effects of the various factors involved in the decomposition process. As can be surmised, the linear dependence points directly towards the total body score. A specific discussion of these results, and the impact they have on the development of time since death equations, will be provided in the discussion section.

Moreover, when assessing the speed at which each depositional environment produces specific total body scores, outdoor contexts were observed to require the least amount of time to do so. Although an initial delay was observed, when cases entered into the latter half of the early decomposition stage, outdoor environments were demonstrated to produce a faster rate of decay than indoor cases. The combined non-water outdoor and indoor model also supported the trend shown by the outdoor context.

Finally, after developing a general decomposition model by which to estimate time since death in the Delaware River Valley, a comparison was made with the model derived by Megyesi et al. (2005). When applying the data derived from cases found in Delaware to the Megyesi et al. (2005) model, it was found that the Delaware River Valley model developed in this study explains a larger proportion of the observed variation. In fact, this particular discovery holds true not only at the level incorporating all depositional contexts, but also to the model developed for non-water outdoor and indoor cases.

What's more, when both models were used to predict the accumulated degree days by assessing total body scores in each individual case included in the dataset, and the results subsequently compared to actual observed ADD values derived from the each case, the Delaware River Valley equation more accurately approximated the actual ADD total. In fact, when comparing the mean differential and the average of the absolute value of the differential between predicted and observed values, the Delaware River Valley model proved once again to be more accurate.

More importantly, are the results of the comparison between the non-water outdoor and indoor Delaware River Valley model and the Megyesi et al. (2005) model. The DRV model derived in this study not only outperforms the Megyesi et al. (2005) model, but it does so with remarkable accuracy, with the predicted ADD average being only two points away from the actual observed ADD average. Therefore, it is clear that the model derived in this study is much better-suited to estimating time since death in cases found in the Delaware River Valley region.

When the totality of the results are considered, it becomes clear that not only has a model been developed which is more applicable to the cases in this area, but also that universal time since death models are not warranted. Instead, these results validate the creation of a time since death equation particular to the Delaware River Valley (or a specific region) and confirm the necessity of region-specific formulas. For the very first time, a time since death equation directly applicable to decomposition cases in the Delaware River Valley has been developed.

Chapter Ten: Discussion

Qualitative Observations

Accurate Representation of Decompositional Changes and Patterns in a Region: Development of the Total Body Score

Perhaps the single most important factor in accurately estimating the post-mortem interval is the use of decompositional standards that are specific, particular, and appropriate to the environment in which they are being employed. If the total body scoring system being employed does not accurately represent the specific decompositional changes and patterns which occur in that environment, then estimates of time since death will suffer.

This particular consideration has been indirectly identified in a number of studies. Megyesi et al. (2005) deliberately altered the decompositional descriptions developed by Galloway et al. (1989) to better fit the decomposition observed in their cases and, thus, made them more applicable to the total body scoring system which they had developed. Heaton et al. (2010) also took a similar approach toward the development of their total body scoring system with regard to aquatic cases, altering the decompositional descriptions and patterns described in Megyesi et al.'s (2005) land-based study and the aquatic decomposition research conducted by Hobischak and Anderson (2002). In fact, Megyesi et al. (2005: 2) themselves state that the categories developed by Galloway et al. (1989) "were intended to describe the decomposition process as it occurs in southern Arizona…and so the stages were altered to reflect the process as it occurs in non-desert regions of the United States." This specific statement alone perfectly highlights the critical importance of and need to develop a total body score system designed to reflect the pattern of decomposition for each particular environment.

In order to provide a more intuitive explanation of this point, consider the following example: If a total body scoring system was developed based on the decompositional changes which occur in the Sahara desert, the pattern of decay would reflect a rapid onset of bloating, discoloration, and mummification, little to no evidence of moist desiccation, decreased insect activity resulting in minimal consumption and a high degree of preservation of tissues, and reduced bone exposure. If that particular system was applied to the Delaware River Valley area and used to represent the decompositional changes observed in this particular temperate climate, not only would there be significant gaps in the stages which represent moist decomposition, skeletal exposure, insect activity, and so forth, but it would also require observations of decomposition to be force-fitted into the closest “applicable” category, with that particular categorization not being entirely reflective of the decompositional changes observed.

What’s more, if the decompositional changes in an area are accurately described, it decreases the subjective evaluations which can be derived from observations, and reduces the variation in total body score attribution between evaluators. Precise total body score descriptions function to avoid having to account for the poor representation of decomposition, as well as the loose fit between observed decompositional changes and those descriptions provided in the TBS. In this way, accurate total body score descriptions can serve to decrease inter-observer error, and standardize the total body score attribution process.

It is also crucial to keep in mind the fact that different depositional contexts affect remains in different ways. As described in great detail above, although various factors overlap in regards to their presence across contexts, many variables particular to a depositional environment exist as well. Even though these covariates were not identified as having a statistically significant effect in the model, that does not mean they do not produce an effect on the decay process. In reality, these differences function to alter the decompositional changes and patterns observed between depositional contexts, demonstrated most clearly in the differences described in the total body scoring systems developed for non-water versus water cases. Given the difference in variables factoring into decomposition between aquatic and non-aquatic cases, and, most especially, the difference in the specific decompositional changes and patterns which occur in both sets of environments, separate total body scoring systems accounting for these differences are clearly warranted.

Therefore, when taking these considerations into account, it becomes obvious that one of the most crucial aspects of developing an equation by which to accurately estimate the time since death, is the development of a total body scoring system which precisely reflects the particular decompositional changes and patterns specific to a region and depositional environment. Based on a detailed analysis of the progression of decompositional changes in varying contexts throughout the Delaware River Valley, it was observed that total body scoring systems developed in previous studies from various environments throughout the United States and abroad (see Megyesi et al. 2005; Heaton et al. 2010), as well as the descriptions of decomposition which accompany them, are not directly applicable to the patterns observed in this region.

Thus, two total body scoring systems (see Tables 23 through 28), reflecting the specific characteristics of decomposition as they occur in the Delaware River Valley, were developed, one applicable to non-water outdoor and indoor cases, and another to aquatic contexts. Additionally, descriptions of decomposition were reworded and re-described, to more precisely illustrate the specific changes which occur in the various contexts. Lastly, additional categories, reflecting the multiple phases of the skeletonization stage, were added, furthering the call for the development of more specific categories of decomposition. By doing so, the time since death equations derived in this study are built upon models of decomposition more accurately describing the specific decay changes which occur in the Delaware River Valley.

In conclusion, if total body score descriptions are being used which do not accurately represent the process of decay occurring in the region of interest, then the entire model will be thrown off. Taking this into consideration, given the development of a new total body score system in this study, with additional descriptions, categories, and phases, the Delaware River Valley model is better suited to estimating time since death in this area. Based on these results, it should be used in place of the Megyesi et al. (2005) model. Just as importantly, these results also demonstrate the need for region-specific standards and validate the development of total body score descriptions specific to particular climatic and environmental areas.

Decomposition Characteristics in the Delaware River Valley Region

Given how critically important the accurate analysis of total body score is to estimations of time since death, several key observations have been made regarding the decompositional changes and patterns observed in the Delaware River Valley region.

These observations were compiled throughout this dissertation research study, building upon the experiences gained through the daily determination of the total body score in 80 different cases. In total, they reflect the knowledge developed through analysis of in-person assessments of decomposition, autopsy reports, forensic investigator “on-scene” reports, as well as photographs and additional supplements. These general observations, to be discussed below, are meant to facilitate the assignment of total body score and clarify any issues in the interpretation of decompositional changes, especially in those unfamiliar with the scoring system. They can be characterized as helpful hints to improve the examination of decompositional changes and the evaluation of TBS. Ultimately, they are designed to reduce the subjectivity surrounding total body score assessments and increase the objective nature of these analyses, with the results hopefully bearing out on more accurate predictions of time since death.

General Comments Regarding Total Body Score Assessments

Variation

The most important point to remember when assessing total body score revolves around the fact that decomposition is a variable process. The descriptions provided for each stage in this study are based on “typical” decompositional patterns and are by no means expected to cover every possible decompositional scenario. Sometimes, traits may develop earlier than expected. However, when taken together with the entire picture of decomposition presented, they will be clearly indicative of premature development rather than advanced decomposition. Given this important distinction, in cases where the descriptions listed for each decompositional stage do not perfectly match the observations made regarding the body, the attributed score should be based on the “best fit” and entire picture of decomposition presented, based on the totality of the decompositional changes seen. In such cases, discussion among investigators is encouraged to provide educated assessments of total body score.

Total Body Score Assessments Made on Day of Recovery

As a general rule, when at all possible, assessments of total body score should be based on observations of decomposition made the day of recovery, as the ADD formula accounts for the period between the "date last seen" and "date recovered." When counting accumulated degree days, all temperatures above the freezing point have the potential to impact decomposition. Thus, if bodies cannot be evaluated for the total body score the day of recovery, corpses should be stored in freezers to prevent throwing off estimates of time since death.

Causes of Death

It is important to note that particular causes of death may alter the rate of decomposition. Before delving into this specific topic, the reader should be reminded that, with regard to preference, insects first choose to colonize natural orifices, as opposed to post-mortem incisions, thereby relatively preserving indications of trauma (Haskell et al. 1997). Secondly, with regard to projectile damage, changes due to decomposition do not affect the collection and interpretation of gunshot wound evidence, regardless of moderate or cold temperatures, until the skin is degraded or covered in ice and snow, once again preserving evidence of trauma until the very later stages of the breakdown of a corpse (MacAulay et al. 2009a; MacAulay et al. 2009b). However, this study did not identify any particular results of note regarding incisive or penetrating gunshot wounds to warrant discussion. Rather, this section deals with causes of death related to asphyxiation, heart failure, and the like.

The particular link between these causes of death and the rate of decomposition was noticed early on in the decomposition process when a few cases demonstrated a rapid onset of reddening and marbling of the upper body and face, despite the rest of the corpse exhibiting little to no changes. When the cases were examined and the conditions they faced were identified, a trend was noted between the rapid onset of early decompositional changes in the upper body and cases where the cause of death was listed as asphyxia, heart-related deaths, and the like. Given this connection, it appears as if the pooling and congestion of blood in the head and upper torso results in the specific changes observed. Additionally, as these changes develop early on in the upper body, the lower limbs tend to retain a rather fresh looking appearance.

Moreover, it should be pointed out that a useful indicator of the true decompositional state of the body can be found through an examination of the condition of the hands, i.e. the washerwoman effect, skin slippage, and degloving, because the hands are less likely to be affected by the reddening and marbling developing in the rest of the arm. If the hands do not correspond to the changes observed elsewhere, then consideration should be given to the potential impact of the cause of death on decomposition.

Therefore, in such cases where this may be apparent, the evaluator’s best judgment and experience should be used to determine the total body score, as it will likely reflect lower scores despite the changes to the upper body. In this way, the scores will correspond to the decompositional state of the lower body and prevent overestimation of time since death. Thus, it appears warranted that cause of death is determined prior to estimating time since death in these cases. Given the potential importance of cause of death, this example further demonstrates the need for collaboration and communication between Medical Examiners, forensic investigators, and police personnel to effectively estimate the post-mortem interval.

Clavicles, Upper Ribs, and Genitalia

For the sake of clarity, with regard to the three subsets of the body making up the total body score, the clavicles and upper ribs were defined as part of the trunk or torso. Given the classification of the pelvis as part of the torso, coupled with the location of the sex organs, the genitalia were also considered together with analyses of the trunk. This distinction is also designed to reflect the fact that these areas tend to align with the decompositional changes observed on the torso and are influenced by the presence of bacteria present in the gut and bloating in the abdominal cavity. All other areas of the body correspond to either the head and neck, the trunk, or the limbs.

Focal Bone Exposure

Focal exposure is defined as being related to a point of focus, usually small in nature. When applied to the total body score, focal bone exposure relates directly to small amounts of exposed bone, with the surrounding area overwhelming retaining soft tissue. Specifically, focal bone exposure was quantified in this study as demonstrating 1-10% exposure of the bone in the area being scored. Given the fact that in order to fall into the “advanced decomposition” stage, greater than 10% of bone exposure is required, for the purposes of this study, focal exposure is characterized as falling into either the early or moderate decomposition stage.

Decompositional Patterns in Outdoor and Indoor Contexts

The following discussion will describe the particular decompositional changes and patterns observed in cases exposed to non-water outdoor and indoor contexts. Based on similar decay changes between both types of cases, a joint total body score description was developed for both. A summary of these changes can be found in Tables 23 to 25. The discussion will be broken down by area of the body and decompositional stage.

In comparison to the Megyesi et al. (2005) total body score description, the decompositional changes and patterns described here have been re-interpreted and expanded upon with greater details. The hope is that by providing more information and rearranging key observations among stages and phases, the actual decompositional changes and patterns in the Delaware River Valley area will be better represented. Across each area of the body, the greatest differences between these total body score descriptions and those developed by Megyesi et al. (2005), can be found in the skeletonization stage, where additional categories have been added and expanded upon.

Head and Neck

In comparison to the other areas of the body, the first region to demonstrate evidence of decompositional changes is the head and neck. Although the decompositional changes in the lower abdominal area quickly follow, bloating of the face, along with the purging of fluids, drying out of the nose and lips, marbling, development of a red to green discoloration, and protrusion of the tongue, all appear to occur relatively quickly.

To begin, the fresh stage in the head and neck is characterized by no discoloration and a normal, living look. Once the beginning phases of early decomposition take place, the epidermis begins to demonstrate some slippage, with the skin taking on a pinkish tint. At this point in time, some slight hair loss may be observed. As the early decomposition stage progresses, the skin begins taking on a gray to green discoloration, although some areas may retain a relatively fresh looking appearance. Eventually, a greenish, and sometimes purplish, discoloration predominates over the entire head and neck, with brownish shades developing as the nose, ears, lips, and edges of the face begin to dry. The next phase involves purging of the decompositional fluids out of the eyes, ears, nose and mouth. Given the start of the protrusion of the tongue from the oral cavity, some bloating of the neck and face may also be apparent. A green and/or purple discoloration is likely still visible, possibly having darkened since the previous phase. By this point, no exposure of bone is seen, with about the same amount of drying of the skin as previously described. In the last phase of the early decomposition stage, the flesh takes on a brown to black discoloration. Given the discoloration, some drying over large areas of the face and neck are possible, not to be confused with leatherized or mummified skin. Should the skin not be dry, moist decay will be seen. Some very slight focal bone exposure may be visible. Bloating may also still be present or in the process of waning.

The moderate stage of decomposition in the head and neck is characterized by the development of brown leathery skin. This change in skin texture is more advanced than the simple drying of tissues previously described. In fact, large areas of the face may demonstrate changes consistent with a leathery texture or mummification. These observations of leathery and/or mummified skin often correspond with the simultaneous development of leathery skin in other areas of the body. No bloating is usually present, as the post-bloat phase is typically underway. Some very slight focal bone exposure may be evident as well.

The advanced decomposition stage is marked first by moist decomposition of the tissues. This is in stark contrast to the mummified tissue seen in the next phase. Both phases demonstrate bone exposure no greater than half of the head and neck.

The final stage of decomposition in the head and neck is characterized by skeletonization. In the early phases, bone exposure of more than half the head and neck is seen, with decomposed, moist, and greasy tissues and substances observable. The next phase is also characterized by bone exposure of more than half the head and neck, but the tissue is either desiccated or mummified. Given the presence of some remaining tissue, hair may still be adherent to the head in remote locations. The following step is marked by either only slight tissue adherences or bones completely devoid of soft tissue. Due to the potential adherence of very small areas of remaining tissue, the bones still retain grease and a greasy appearance. Next, following the removal of all or nearly all tissue, bones tend to be found scattered away from the main cluster of the body due to animal activity in this phase. Subsequently, in the ensuing phase, any bones found are largely dry, although some grease remains. No soft tissue adherences are observed at all. The final phase of the decomposition process in the head and neck demonstrates dry bone in varying states of deterioration.

Torso

With regard to the decompositional changes and patterns in the trunk, the fresh stage is characterized by no discoloration and the normal appearance of tissue. The early decomposition stage begins with the development of a pinkish tinge to the skin, with marbling and some skin slippage possibly also occuring. As the next phase begins, a gray to green discoloration takes hold, usually restricted to the lower abdominal area. Some flesh retains a relatively fresh appearance. In the last phase of the early stage, bloating is clearly visible, with green discoloration observed throughout the body. This particular phase tends to correspond with the purging of fluids from the anus, mouth, ears, and nose. The body may also take on a darker purple or purple-red color. Occasionally, black, and sometimes brown discoloration is observed, along with the requisite areas of drying skin.

The moderate decomposition stage is characterized by a post-bloat appearance following the release of abdominal gases. If not yet observed, discoloration has changed from green to black by the first phase. During the latter portion of the opening phase, decomposition may produce the sagging of tissue and the caving in of the abdominal cavity. In the next phase, the skin takes on a leathery and parchment-like appearance. Given the deflated look, in combination with the skin texture observed, a wrinkled appearance of the skin is often seen. By this phase, larger areas of skin may be at the point of mummification. However, very slight to no focal bone exposure is observed.

The advanced decomposition stage in the trunk is characterized by the same changes observed in the head and neck. Moist decomposition is first seen, with bone exposure of less than half the torso. This phase is followed by the appearance of mummified tissue in conjunction with less than half the trunk demonstrating bone exposure. However, compared to the previous stage, both advanced decomposition phases show greater than 10% bone exposure.

Lastly, the skeletonization stage begins with the loss of significant amounts of soft tissue, with bone exposure making up more than half of the torso. The next step involves the presence of mummified or desiccated tissue totaling less than half the trunk, predominantly demonstrating bone exposure. The following phase shows little to no soft tissue adherence, given the complete collapse and consumption of soft tissue and muscles. Occasionally, a sludge-like glob is seen encompassing the bone with this having a sticky and putty-like texture. This moisture, coupled with the continued presence of marrow, cause the bones to retain grease. The ensuing phase features the scattering of bones away from the main cluster of the body due to animal activity. Next, bones are found in a mostly dry state, with some traces of grease remaining and no evidence of soft tissue present. Lastly, only dry bone remains, found in various stages of breakdown.

Limbs

As discussed above, the head and neck region tends to be the first area of the body to demonstrate decompositional changes. However, the limbs are normally the last to produce changes consistent with decay. This may be due in large part to the differential diffusion of gases between the head, torso, and limbs, as well as the inability of bacteria to spread as quickly into the arms and legs. Unlike the trunk, head, and neck, the limbs lack passageways for the spread of gas and bacteria, ultimately resulting in a slower rate of decay.

The stages of decomposition involving the arms, legs, hands, and feet, are not as numerous compared to the other two areas of the body. As in every region, the fresh stage is characterized by normal looking skin and no discoloration. Upon the beginning of the early decomposition stage, a pinkish appearance develops, with skin slippage observed in the hands and/or feet. Some slight drying of the fingertips and toes may be possible at this point, but overall, the skin retains a nearly fresh appearance. The next phase demonstrates gray to green discoloration and evidence of marbling. The potential exists for the presence of dried skin on the fingertips and toes, although this observation is seen most often in indoor cases. At this point, some areas of skin may still retain a relatively fresh appearance. The last phase of early decomposition in the limbs shows greenish and/or purplish or purplish-red discoloration. Dry brown shades, predominantly clustered at the edges of the hand and feet are observed, along with drying of the fingers and hands, toes and feet, heels, and knuckles. These areas of dry skin may extend to somewhat larger areas on occasion. Gloving of the skin of the hands and feet is possible in this phase.

The moderate decomposition stage is marked by the observation of brown or yellow-brown leathery or mummified skin. Little to no focal bone exposure is seen. Given the typical leathery appearance of the skin, brown to black discoloration predominates. A dry, wrinkled appearance is sometimes observed. The hands and/or feet may be mummified, with the potential for large areas of skin to be at the point of mummification. This particular stage is distinguished from the previous phase by the state of the lower legs. If the lower legs have yet to mummify and still exhibit traits characteristic of early decomposition, such as purple and green discoloration and skin slippage, the earlier phase should be used.

The advanced decomposition stage of the limbs is the same as that described for the head, neck, and trunk. It begins with moist decomposition and more than half the soft tissue remaining, and concludes with mummified tissue and more than half the tissue remaining.

The final stage in the decomposition of the limbs begins with the exposure of more than half of the bones of the limbs, with decomposed tissue remaining. The next phase also shows exposure of more than half of the bones of the limbs; however, desiccated or mummified tissue remains. The following phase is defined by the presence of slight to no soft tissue adherences, although the bone retains grease. The subsequent phase is characterized by the scattering of bones away from the main cluster by animals. The penultimate phase is marked by largely dry bone, although some traces of grease remain. However, no soft tissue adherences remain on the bone. Lastly, dry bones remain in various stages of deterioration.

General Comments Regarding Decomposition in Outdoor and Indoor Contexts

This specific section is dedicated to a few points of consideration in regards to issues to keep in mind, specific patterns of note, information pertaining to particular variables, and so forth.

<u>Multiple Stages</u>

Given the overlap between decompositional stages, it should be noted that in some cases, artifacts of previous stages may be retained. For example, dried purge fluid may remain despite the body progressing through to stages characterized by extensive bloating. If traits of the next stage are developed, even with artifacts of previous stages remaining, it should be scored as such, so as to reflect the progression through to more advanced stages of decomposition.

Unequal Decomposition

Oftentimes, unequal decomposition can be observed between the anterior and posterior surfaces of a body. In fact, the side of the body touching the ground often shows putrefactive changes, while the opposite side may show drying, induration, or mummification. This observation may be due in part to the gravitational pooling of blood, especially during the early stages of decomposition, as increased reddening and purpling in dependent areas is more often than not reflective of livor mortis.

Along the same vein, when a body is found lying face down, the skin of the face often looks collapsed and pushed in. This should not be confused with trauma. Likewise, care should be taken not to characterize this pseudo-collapse of facial tissue as evident of post-bloat stages, if accompanying traits in the rest of the body do not support such a characterization.

Putrefactive Changes

In regards to observable decompositional changes, although the abdomen would show green discoloration in the lower quadrants, noticeable putrefactive changes appeared to progress quicker in the face. These changes included visible discoloration, purging, and bloating, which appeared to develop quicker than in other areas of the body.

As was observed in regards to the progression to skeletonization, the arms were quicker to progress through decomposition than the legs, especially in regards to developing a green discoloration, as well as the development of leathery and mummified skin.

Dried versus Leatherized versus Mummified Skin

Care should be taken to distinguish between dried, leatherized, and mummified skin. On a number of occasions, forensic investigator and autopsy reports appeared to over-estimate or exaggerate the degree of desiccation, when in fact, the skin was simply demonstrating dry patches or leathery skin as opposed to complete mummification.

Dried skin typically develops earlier on during the decomposition process and in addition to being brown, can be accompanied by black and dark purple discoloration, bloating and sometimes purge fluid.

Leathery skin occurs during the more moderate stages, oftentimes retaining a parchment-like look and feel, as well as a wrinkled appearance. It can often be found during post-bloat periods. Mummified skin is completely dried and brown in color.

When uncertain whether skin is in a leatherized or mummified state, if skeletonization beyond focal exposure of bone is apparent, the case tends to minimally fall into the advanced decomposition stage characterized by "mummification with bone exposure less than one half that of the area being scored." Obviously, if greater than half of the area being scored is skeletonized, it will fall into the "skeletonization" stage.

However, an exception to this general rule was discovered in cases involving hangings in the woods during the summer months. During this period, the body quickly mummifies, often precluding insect activity (as flies require moist tissue to oviposit their eggs). Additionally, given the hanging of the body, it is sometimes inaccessible to scavengers. In these cases, despite the lack of skeletal bone exposure, given the high degree of mummification, complete loss and dehydration of internal organs, and so forth, the case is typically scored minimally as "mummification with bone exposure less than one half that of the area being scored." If this is not done, and the body is scored into an earlier stage of decomposition, an underestimation of time since death will result.

Given the retroactive nature of this study, this research had the added benefit of knowing the PMI period before assessing total body score. Typically, those cases not demonstrating bone exposure were seen to be exposed to shorter PMI periods. However, in the handful of cases in which individuals were found to be hanging in the woods, a longer time since death interval was seen. Thus, by scoring the body into a later stage of decomposition, the total body score is not hampered by the atypical lack of skeletonization seen in these cases.

Body Weight, Age, and Mummification

In support of studies suggesting differences in the rate of decomposition in regards to variations in body weight and composition, oftentimes it was observed that in older individuals with lower body mass indices, progression to mummification was quicker than those with more bulk. The reduced body mass appears to speed up the dehydration of tissues and support preservation, seen especially in indoor cases. In this study, direct observation supports the notion that individuals with little body fat and light weight, seen most often in the elderly, may progress to the dry decay phase more quickly than heavier individuals. The result of this process is a corpse with dry, leathery, and oftentimes mummified skin, especially in indoor environments.

However, much like all of the variables discussed in this study, the progression through the stages of decomposition can be heavily altered by the effects of temperature, humidity, and aridity. For example, a low weight, low body fat individual decomposing next to a portable heater, will most likely present a rapid progression to mummification.

On the other hand, if the same individual was left to decompose in a bathtub full of water, the low weight and fat would be counteracted by the moisture present around the body. Thus, noting the circumstances under which a set of remains is found is crucial to determinations of time since death.

Progression to Skeletonization

Skeletonization was most often seen first in the cranial bones, beginning in the area of the forehead and orbits, and progressing downwards. The back of the head and zygomatic areas typically took longer to be exposed. This may be due in part to the protection afforded by hair, in the case of the back of the skull, and the fatty tissues encompassing the cheeks, in regards to the exposure of the zygomatic bones. After the exposure of the cranial bones, the trunk followed suit, beginning with the clavicles, vertebrae, and then ribs. In the limbs, the upper arms seemed to show skeletonization first, typically involving the bicep/tricep/deltoid area or the proximal aspect of the humerus. The hands were often exposed during this time as well, especially the distal phalanges and the junction surrounding the metacarpals and proximal phalanges. Lastly, the ends of the bones, including the elbow area were exposed. The lower limbs appeared delayed in regards to skeletonization, while the gut was rarely described given the lack of skeletal elements in the area.

Insect Activity

Firstly, since bodies were scored based on information presented in the Medical Examiner’s autopsy reports, only the insect activity noted during autopsy was used for scoring. This particular distinction was made given the observation that forensic investigator reports describing insect activity on scene were not consistent across all investigators regarding insect presence, infestation, artifact, and absence. At times, vague or inconsistent terminology was used, making it difficult to develop a clear understanding of insect activity on the body. Therefore, only the information presented in the autopsy report was used for this assessment. This issue points at the need to standardize the reporting of information on scene, not specific to just insect activity, but across the entire spectrum of variables including temperature, clothing, scatter, shade/exposure, and so forth. This will be discussed in more detail in subsequent sections. However, a question remains regarding if assessment of insect activity by Medical Examiners in autopsy reports is biased by observations of where the most decomposition has occurred.

In regards to the presence and location of insect activity, oftentimes maggot activity is observed on the head and neck area, and sometimes upper torso, resulting in the exposure of the cranial bones of the face, clavicles, upper ribs, and possibly some of the shoulder girdle. Insects were not often seen to colonize the limbs, especially the lower extremities. If present, insect activity was usually found first on the head and neck, then upper torso, followed jointly by the upper extremities/torso/pelvic girdle. Lastly, as a general observation, traumatic areas tend to be accompanied by insect activity as well.

Scattering

In regards to the scatter pattern of the skeleton, the cranium appeared to be among the first skeletal elements to be subject to scatter, as it is usually disarticulated from the mandible (which will scatter as well). Given the circular shape of the cranium, it is subject to both rolling and transportation by scavengers, who can easily grab hold of the cranial bones by the orbital sockets. Following the cranial skeleton, the postcranial elements which tended to scatter next were the ribs, bones of the hands and feet, and bones of the lower arm (radius and ulna). Often times the lower extremities remained intact, likely due to the influence of cartilage, tendons, ligaments, and so forth.

In cases where significant tissue is still adhered to the bone, but the bone is scattered away from the main cluster, it should be scored as still retaining slight tissues adherences, so as to not over-score an area if not warranted. Additionally, bones tended to be scattered before they developed a largely dry appearance. For the sake of consistency in scoring, if the reverse is seen, the area should still be scored as "bones scattered away from main cluster of body due to animal activity."

Trauma

In cases of trauma in a particular location, the immediately surrounding area may appear to be in a more advanced stage of decomposition than the rest of the body region. However, it should not be classified according to that advanced decomposition, but instead should reflect the stage of decomposition represented by the rest of the area, as the trauma may have contributed to increasing the rate of decay about the wound. If this not done, it will lead to over-scoring and will not appropriately describe the time since death. For example: Should an individual have died via a gunshot wound to the head, the immediate area surrounding the wound may display increased insect activity, drying, skeletonization and so forth. However, one must consider the state of the rest of the head and neck, such as if the eyes are collapsed, hair is still attached, and skeletonization is present elsewhere, so as to properly score the state of decay.

Decompositional Patterns in Aquatic Environments

Compared to the non-water outdoor and indoor total body score descriptions described above, the decompositional changes and patterns observed in aquatic environments correspond to fewer stages and phases. What's more, these changes were observed to be more difficult to generalize, as more variation appeared to characterize aquatic cases. As a result, significant overlap exists in regards to some of the descriptions provided. A summary of these changes can be found in Tables 26 to 28. The discussion will be broken down by area of the body and decompositional stage.

Much like the method utilized in regards to the total body score descriptions described by Megyesi et al. (2005), the decompositional changes and patterns discussed in Heaton et al. (2010) were re-interpreted and expanded upon in order to be more representative of the decay process as it occurs in aquatic cases in the Delaware River Valley. As a result, additional phases were included in regards to skeletonization and discussed in detail.

Continuing the conversation regarding variation, it is important to note that unlike the patterns and changes observed in the non-water outdoor and indoor cases, much greater variation in the decomposition process is seen in cases deposited in aquatic contexts. Multiple regions of the body may be in different stages of decomposition at once in one case, but show equal decay in another. In terms of the beginning of decay, although the head and neck, followed by the trunk, often show the first signs of decomposition, the hands are quick to wrinkle and take on a white coloration. They do not appear to lag as far behind in developing decompositional changes compared to the limbs in non-aquatic cases.

Moreover, a greater range of colors observed on the body is seen in aquatic cases. In addition to the traditional reddening and green discoloration, changes from purple to black to brown, and even to blue, are often seen. These colors do not necessarily correspond to specific phases, oftentimes lingering later on in the process or demonstrating multiple colors in the same region of the body at once.

In total, based on the inconsistencies observed in the decomposition of bodies deposited in aquatic cases, it is certainly safe to conclude that variation is the rule in aquatic decay.

Head and Neck

Across each of the three regions of the body, the fresh stage is characterized by no visible decay changes. In the first phase of the early decomposition stage in the head and neck, a slight pink tinge develops on the skin, corresponding with darkened lips, usually blue in color, and goose pimpling. As the next phase develops, reddening, which can sometimes be dark, begins to be observed on the face and neck. Initial skin slippage and marbling also develop in this phase. Additionally, the potential for early signs of animal activity and predation are possible, concentrated mainly on the ears, nose, and lips. Early evidence of bloating, especially in the tissues of the lips, may be seen at this point. Head hair may also begin to slough off, seen mostly at the front in this phase. Occasionally, some purging of fluid may be observed. Internally, the brain begins to soften, with potential liquefaction in a small number of cases. The next phase is marked by clear evidence of bloating in the face and neck. Discoloration, ranging from yellow-brown to light brown to green, is seen. At times, some evidence of reddening remains. At this point, skin sloughing is in full effect, along with the sloughing of head hair, and sometimes, the complete sloughing off of hair. Evidence of animal activity may have become more prevalent on the ears, nose, and lips, with the potential exposure of some underlying tissues of the face, neck, and orbits. Purge fluid may continue emanating from the orifices or be in the process of waning. Internally, the brain is completely softened and nearing, or completely at the point of, liquefaction.

The moderate stage of decomposition in the head and neck is characterized by the post-bloat phase. At this point in time, the face has taken on the look of more advanced decomposition, including dark green and black discoloration, but with no significant bone exposure. Instead, tissue can be exposed on the face and neck, with the potential collapse of the anterior aspect of the face, especially the nose. In terms of head hair, it is often seen to have completely sloughed off by this time. Internally, the brain is usually fully liquefied, with no remaining structure.

The advanced decomposition stage is denoted by less than half of the bone being exposed. Those areas demonstrating bone exposure tend to concentrate over the orbital, frontal, and parietal regions of the skull. Some bone exposure is occasionally seen on the mandible and maxilla. The next phase involves more extensive skeletonization of the cranium, exposing greater than half of the bone. Given the breakdown of tissue and accompanying connective fibers, the disarticulation of the mandible is observed at this point.

Lastly, the first phase of the skeletonization stage in the head and neck is marked by the disarticulation of the skull from the trunk. Some slight adherences of soft tissue may remain adhered to the bone. Given the fairly recent exposure of extensive areas of the bone, an off-white or light brown color is retained. The last phase demonstrates the bones of the skull completely devoid of any and all soft tissue. The bones are typically white in color, almost as if they were bleached, although some areas of light brown colorations or staining from mud may be evident. As time progresses, evidence of erosion and weathering may be seen.

Trunk

Immediately following death, the fresh stage of decomposition produces no visible changes. At the beginning of the early decomposition stage in the torso, slight pink discoloration, as well as goose pimpling of the skin, is observed. This phase is followed by the development of yellow-green and light-green discoloration of the abdomen and reddening of the upper chest. Depending on the position of the body, reddening is occasionally seen on the sides of the trunk. At this point, marbling is also observed to be beginning, along with initial slippage of the skin. In regards to the scrotum in males, bloating may be observed in this region. Early signs of predation are possible in this phase, not concentrated over any particular area. Internally, the organs are beginning to soften. Despite all of these changes, some areas of skin may retain a relatively fresh appearance. Moving on, the next phase is marked by mild to full-on bloating of the abdomen and scrotal sac in males. The scrotal sac may have begun bloating earlier than the abdomen, so it may be more advanced in that respect. Additionally, yellow and light to dark green discoloration, which may sometimes appear blue, is seen. Possible reddening and marbling may remain as artifacts of the previous phase. Skin slippage is clearly observed. Internally, organs show evidence of autolysis, complete with marked softening.

In the moderate stage, dark green or purple discoloration is observed. No reddening or yellowing is seen. Bloating of the abdomen remains at this point. Based on the position of the body during flotation, which is usually face down, the skin on the side facing the sun may appear brown and dried or even leathery.

The advanced decomposition stage begins with black discoloration and the softening of the abdomen following the gradual loss of bloating. The internal organs may be exposed in areas, along with slight focal exposure of bones such as the ribs, sternum, and so forth. Given the potential breakdown of the torso, the organs are typically in an autolytic and liquefied state. Should the body have been floating for an extensive period of time, the side facing the sun, which is typically the back, may show the development of leathery or mummified skin. Conversely, the black discoloration typical of this phase may also make way to the presence of a white-cheesy substance, characteristic of adipocere. Should the quantity of adipocere not be in large amounts, the total body score can be assessed. In cases of large degrees of saponification, caution should be utilized when applying the standards, given adipocere's preservational qualities. A discussion regarding the application of the time since death estimation formula to bodies exposed to atypical conditions or contexts can be found in subsequent sections. Continuing on, the next phase of advanced decomposition in the torso shows further loss of tissues and organs. Bone exposure is more extensive than that seen in the previous phase. However, the total amount of exposure is less than half.

In the skeletonization stage, the first phase begins with greater than half of the bone being exposed. Soft tissue is still adherent to the bones, and little to no traces of organs remains. The following phase shows complete skeletonization and disarticulation of skeletal elements, with only slight, if any, tissue adherences. At this point, the bone still retains an off-white or light brown color. Lastly, the final phase is marked by the presence of nearly, or completely, bleached bone, devoid of any soft tissue. Based on the length of the post-mortem interval, evidence of erosion and weathering may be visible.

Limbs

Exactly as described in the other regions of the body, the fresh stage of decomposition does not produce any visible changes. However, the remaining stages focus extensively on the decay changes observed in the hands and feet. These changes begin in the first phase of the early decomposition stage, characterized by mild wrinkling of the skin of the hands and feet, along with possible goose pimpling. The next phase is marked by the development of a white, wrinkled, and thickened appearance of the skin of the palms of the hands and the soles of the feet. These changes are known as the "washerwoman effect." Additionally, slight pink discoloration of the arms and legs is visible, along with possible early signs of marbling and slight focal skin slippage in select areas. The fingertips and toe, along with muscles of the arms and legs, may show possible early signs of animal activity and predation. Despite all of these changes, some areas of skin may still appear relatively fresh, especially in the lower legs. The final phase of early decomposition demonstrates soggy and loose skin on the palms of the hands and soles of the feet, with the potential sloughing off of some of the skin of the hands. However, what separates this phase from moderate decomposition is the state of the feet. In this phase, the feet tend to be in a less advanced stage of decomposition when compared to the hands. Continuing on, marbling or dark reddening, which occasionally appears purple, is clearly visible in the limbs, predominantly concentrated on the upper arms and at times, the upper legs. Initial skin slippage may also be observed throughout the limbs. Discoloration of the arms and/or legs is often seen, taking on a yellow-brown, light green, and occasionally blue color. Signs of predation may be apparent.

In terms of the moderate decomposition stage, the skin of both the hands and feet are sloughing off or has completely degloved. Skin slippage is also seen throughout the arms and legs. A yellow-brown, green, greenish purple, or black discoloration is observed on the arms and legs. Clear evidence of predation may be visible. Moreover, much like what was seen in regards to the torso, the skin of the arms and legs on the side facing the sun may appear brown and dry or leathery.

The advanced decomposition stage begins with focal exposure of the bones of the hands and/or feet. Given the small nature of these bones, some may be lost by this point. Underlying muscles, tendons, and focal areas of bone may be exposed in the lower arms and/or legs. Based on the position of the body, the posterior aspects of the skin may appear leathery or mummified. The following phase shows definite disarticulation of the bones of the hands and/or feet, with some soft tissue potentially remaining adherent. At this point, more than half of the soft tissue remains on the bones of the upper arms and/or legs. The next phase demonstrates the same characteristics, except less than half of the soft tissue remains on the bones of the upper arms and/or legs, displaying significant bone exposure.

The skeletonization stage begins with the complete skeletonization and disarticulation of the limbs, with only slight, if any, soft tissue adherences remaining. The bone retains its off-white or light brown color. Lastly, the final phase in the decomposition process is marked by bones completely, or nearly completely, bleached white. The bones are devoid of any and all soft tissue. Based on the length of the post-mortem interval, the effects of erosion may be visible.

General Comments Regarding Decomposition in Aquatic Environments

This specific section is dedicated to a few points of consideration in regards to issues to keep in mind, specific patterns of note, information pertaining to particular variables, and so forth.

Variation

To begin, as discussed above, variation in decomposition is the rule, not the exception. This point is exacerbated in aquatic environments where it appears decomposition is even more variable than changes seen on land in both outdoor and indoor contexts. This point is highlighted by the small amount of variation in decomposition explained by the models developed for this specific depositional context, especially when using post-mortem interval days. Even more so, the low coefficient of determination highlights the existence of a multitude of additional factors which not only alter the decomposition process, but are very difficult to retroactively track back in time. Variables such as current, tide, location in the water column, changes in salinity and pH level, and so forth, may all impact decay and thus contribute to the variation observed.

What's more, this variation is exacerbated by differences in the salt content of the water source. Specifically, freshwater cases are said to exhibit stages of decomposition that are only slightly modified from the stages demonstrated in terrestrial environments (Hobischak and Anderson 1999; Hobischak and Anderson 2002; Anderson and Hobischak 2004). Marine depositions on the other hand, often demonstrate bloat, active, and advanced stages simultaneously, accumulating greater amounts of intestinal gas, leading to flotation (Anderson and Hobischak 2004). Fortunately, marine depositions dominated this study, tied in to the inability to obtain accurate temperature data from freshwater ponds, lakes, and so forth. However, the pattern of decomposition observed holds true, corresponding with Anderson and Hobischak's (2004) claims.

Oftentimes, different parts of bodies appeared to be in various stages of decay at once. Given the difficulty in assessing total body score under such circumstances, decisions needed to be made regarding the stage demonstrating the majority of the changes observed. Thus, especially in the case of aquatic depositions, decompositional descriptions and the associated scoring system need to be approached with a "best fit" mindset, taking into account the state of the entire body and known conditions.

Internal versus External Decompositional Changes

Additionally, the scoring system accounts for both internal and external decompositional changes. However, given the highly variable nature of internal decomposition, such as the timing of the softening versus liquefaction of brain tissue, the description of the decomposition of the organs should serve more as a guide to corroborate observations made regarding external changes, rather than a clear-cut, and definitive description of decomposition in all cases.

Bloating

In terms of the pattern of bloating seen in aquatic contexts, the weight of the individual in question is a very important factor to consider. Individuals with a large fat content prior to death will present issues concerning the evaluation of bloating and extreme bloating versus their normal appearance during life. Oftentimes, it was difficult to discern large stomachs from bloating, especially heavy bloating. Clearly, given the need to identify the presence and degree of bloating for the purposes of determining the total body score, this issue must be looked at closely.

However, a useful indicator to resolve this particular problem deals with the tension felt in the abdomen and torso. Typically, the buildup of gas will present a tense abdominal surface, while an abdomen with a large concentration of fat will be softer to the touch. Once again however, caution should be taken not to confuse the softened feel of peri-mortem fat buildup with the deflation of the abdomen following the release of decompositional gases, although by that point in the decompositional process, additional characteristics such as dark discoloration, extreme slippage of the skin, and bloating of the genitalia will have occurred. In particular, the scrotum appears to often bloat before the abdomen, another useful indicator when observing bloating.

Assessing Decomposition in Mud-Covered Bodies

Moreover, given the nature of aquatic depositions and the sinking of a body before the development of gases, the corpse is oftentimes found to be covered in mud from interaction with the ground surface. Before assessments are undertaken, efforts should be made to view the actual skin surface to allow the proper observation of decompositional changes. However, extreme caution should be taken to avoid the removal of skin, as this is possible when skin slippage commences. In such situations, it may be more effective to wash or wipe clean only select areas in each of the three regions of the body.

Blunt Force Trauma

In regards to the earlier stages of decomposition, much like the decay process described for outdoor and indoor bodies, a corpse typically demonstrates a reddened discoloration, followed by purpling of the skin. The reddening is nearly always seen, tied to livor mortis development and the pooling of blood in dependent areas. The purpling however, may not only be the result of livor mortis and increased discoloration, moving from red to purple, but may be indicative of blunt impact as well, as this characteristic was often seen in cases of bridge jumpers impacting the water surface at high rates of speed, from high altitudes. Once again, this particular observation points to the importance of the evaluation of cause of death when evaluating decompositional changes.

Marine Animal Activity

On a number of occasions, bodies were found with clear evidence of marine animal scavenging activity. Given the diversity of marks observed, a variety of organisms appeared to directly interact with corpses beginning in the earliest stages of decay. In addition to the more obvious culprits, fish and crabs, barnacles and shrimp were sometimes seen adhered to corpses as well.

In regards to the particular pattern of involvement with bodies, evidence of marine animal scavenging activity was typically first seen in the area of the ears, nose, and lips, manifested as bite marks and pieces or chunks of missing flesh. As the early phases of decomposition progressed, evidence of animal activity became more widespread, with exposure of some of the underlying tissues in the face, neck, and orbits. These changes tended to appear before marine animal modifications of the limbs and especially the torso, although animal activity in the arms and legs were sometimes seen in conjunction with that of the face. In terms of marine activity on the limbs, missing tissue was sometimes seen on the fingertips, knuckles, and fleshier areas of the arm, such as the bicep/tricep/deltoid region. The torso was not particularly remarkable in regards to marine activity, but occasionally would show small bite marks scattered about. Although subject to variability, these aforementioned changes were clustered in the early stages of decomposition and were not noteworthy enough, or readily apparent beyond the moderate stages, to warrant additional description.

Single bone recovery

Oftentimes, given the nature of aquatic deposition, fluvial transport of body parts and bones is a common complication in the recovery of remains. At times, only a single bone or a handful of bones are recovered. Given this fact, strong caution should be taken in regards to estimates of time since death on single bone recoveries, utilizing the standards and formulas developed in this study. This statement is supported by the fact that police personnel will undoubtedly use any time since death parameters defined by forensic investigators to exclude individuals as contributing the unidentified remains and help push along a case. Given the wide variability which exists in the later stages of decomposition, this tactic may unjustly exclude individuals and preclude investigations. Therefore, if an estimate of time since death under such circumstances must be produced using the information presented here, a wide error estimate should be employed to prevent such issues.

In practice, during cases where only single bones or a handful of bones are recovered, given the inability to determine the state of the remaining bones of the body (such as if they are bleached white, devoid of soft tissue, and so forth), the other areas of the body should be scored based on complete skeletonization and disarticulation only. In this way, an assumption is made that the remains are at the same stage of decomposition as the bone found, but not further along in the process.

Adipocere

The development of adipocere is a highly complicated process requiring the alignment of multiple factors. As illustrated first by Mant and Furbank (1957), and coined later by O'Brien (1997) and O'Brien and Kuehner (2007), conditions must be "just right" for adipocere to form. These conditions include a moist environment, warm temperatures (21-45 degrees C), bacterial action, anaerobic conditions, and adipose tissue, with additional variables such as relative humidity and pressure playing a role as well. However, although adipocere can form in conditions such as full submersion, complete immersion in water is not necessary for development (O'Brien and Kuehner 2007). Likewise, although an optimal temperature range exists, consistent temperatures are not required (2007). Therefore, despite the understanding of a number of variables known to alter the development process, a high degree of variability, as well as the need to identify as-yet-unknown factors involved in formation, exists. When this fact is coupled with the inability to track all conditions impacting a set of remains through the entirety of the post-mortem period, a high degree of unpredictability in the process of adipocere development becomes clear. What's more, sometimes white mold formation may be mistaken for adipocere, further confusing matters. As a result, it becomes relatively difficult to pinpoint the stages during which adipocere formation begins and fully develops.

In this particular study, the high degree of variability inherent in the development process was blatantly obvious. Adipocere formation was sometimes observed to have developed by the advanced decomposition stage, but also as early as the late early/moderate stage or even later on in the process as more exposure of the skeleton was observed. Most often however, adipocere was not observed at all. This variation in the onset and full development of adipocere corresponded with the variability described by Anderson and Hobischak (2004), Forbes et al. (2004), Pakosh and Rogers (2009), and many more. Moses (2012) even demonstrated the ability of adipocere to form on defleshed bones, as residual adipose and lipids are sufficient for production. Importantly, the stage of adipocere development could not be attributed to the duration of burial (2012).

In Forbes et al.'s (2004) study, one sample exhibited advanced adipocere development, even when compared to another sample with a similar submersion interval. Another sample had a prolonged submersion interval, yet demonstrated a similar adipocere chemical composition as samples exposed to shorter submersion timeframes. Based on these results, Forbes et al. (2004: 8) conclude, "adipocere composition cannot be directly linked to decomposition interval…and hence it appeared that factors present in the decomposition environment must have influenced the rate and degree of formation." Thus, the variability in the adipocere formation process observed in this study, as well as several others, lends credence to claims suggesting that adipocere development is still not yet completely understood.

Therefore, given the highly unreliable nature of adipocere formation and the inability to pinpoint the stages during which such indications develop, descriptions of adipocere were removed from the scoring system. By doing so, it is also hoped that individuals scoring the decomposition on a body are not using the presence or absence of adipocere as a defining characteristic of a particular stage, as such indications may not even develop at all. Lastly, given the ability of adipocere to preserve remains in an adipocerous state, coupled with an extreme lack of understanding concerning its impact on the accuracy of time since death estimates, fully saponified bodies were removed from the study to avoid including potentially confounding factors. This particular decision is supported by Heaton et al. (2010), who argue that given the ability of adipocere to delay or even halt decomposition past a certain point, despite ADD increasing, the result will be a much wider variation of decomposition scores for cases with higher ADD values. Most importantly, they state, "Extreme care should therefore be taken when applying this model to cases where adipocere is present." The same conclusion holds true for this study.

Body Position

One last important point to note concerns the fact that decomposition in marine environments is often associated with bodies found to be floating in the prone position. This particular tendency to float face down is related to the buildup of gaseous materials in the trunk, combined with the density and bloating of the face. As a result, given the fact that the anterior aspect of the body is typically the surface which interacts with the water, these standards are based on and designed for assessment of the anterior plane. However, they can theoretically be applied to the posterior surface should the corpse be found floating face up. The only drawback with applying these decompositional descriptions to the posterior surface is that most of the changes described in the scoring system relate to aspects of the body located only on the anterior plane (such as bulging of the lips, bloating of the abdomen, face, and scrotum, and so forth). This consideration should be kept in mind when attempting to identify the correct decompositional stage in supine facing bodies.

General Comments Regarding Decomposition in All Contexts

Incorrect Attributions of Discoloration

One very interesting point to note involves the interpretation of decomposition in darker skinned individuals. Based on descriptions of skin color changes in autopsy reports versus those demonstrated in photographs, it was noted that Medical Examiners consistently mistook darker skin color for green and purple discoloration of the body and vice versa. In reality, it appeared as if the individual was in the very early stages of decomposition, not yet having progressed through to full green or purple discoloration. The exact opposite, in which discolored skin was developed but mistaken for darker pigmentation, appeared to have occurred as well. Moreover, in general, it appears as if descriptions in autopsy reports show greater variation in terminology and the interpretation of changes in individuals of darker skin.

Given the darker hue of the skin, this particular distinction can be difficult to distinguish and appears, oftentimes, mischaracterized. As a matter of fact, the author occasionally had difficulty discerning discoloration in darker skinned individuals as well, especially given the retroactive use of photographs to discern decomposition as employed in this study.

Regardless, this point is of particular importance because it can lead to the over-estimation of the post-mortem interval by incorrectly attributing discoloration or failing to notice it, thus skewing the total body score. Therefore, having stated such, it is of critical importance that Medical Examiners and forensic investigators take caution in identifying true discoloration versus that which may be feigned by the nature of the skin color.

Incorrect Attributions of Degloving

In addition to the points stated above, Medical Examiners and forensic investigators were also often noted to frequently confuse skin slippage or sloughing of the hands/feet, for degloving. As it applies to the hand, complete degloving should constitute the complete separation of the epidermal layer from the underlying dermis, rather than the patchy flaking off of skin characterizing slippage and sloughing. This error is made worse in cases where the hands demonstrate the “washerwoman” effect, a condition in which the hands become rough, white, and wrinkled from prolonged immersion in water. Given that washerwoman hands occur before skin slippage and degloving, these terms, and their identification, should not be confused.

Although there is room for debate regarding the definition of these conditions, for the sake of clarity and accuracy, complete degloving should be universally understood as the removal of the epidermal skin of the hands, not the patchy flaking characterizing slippage. Obviously, gradations and overlaps exist between extensive skin slippage and partial degloving, so caution must be taken. Ultimately, care should be taken to accurately define the condition of the hands and feet not only to prevent mischaracterizations of time since death, but to also standardize these descriptions across autopsies and facilitate the use of commonly understood terminology between all medico-legal death investigators.

Development of Decompositional Changes in the Arms versus Legs

As mentioned briefly above, the arms and legs demonstrated differential decomposition regardless of whether describing the early, moderate, or late stages of decomposition. Importantly, this particular observation was noted across depositional contexts, regardless of environment.

In the early stages, the arms were quicker to progress through decomposition than the legs, especially in regards to developing green discoloration, marbling, skin slippage, and so forth. The same point held true when assessing the development of dried, leathery, and mummified skin. In regards to skeletonization, exposure of the upper arm and hands tended to develop before any such changes were observed in the legs.

Unfortunately, a clear reason for these differences is still unknown. It is possible that such changes are related to a faster progression to decomposition in the upper half of the body, perhaps linked to the spread of bacterial activity and bloating upwards through to the torso, thoracic area, neck, and head. However, the question remains as to why such a progression is not as rapidly observed in the upper legs.

Additionally, the presence of clothing on the lower legs and feet may account for these differences, as the arms and hands tend to be relatively uncovered in many cases. However, the link between clothing and alterations in the rate of decomposition are still up for debate, potentially showing reduced tissue breakdown in clothed corpses, due to the difficulty of accessing remains by scavengers. Regardless, the difference between these two areas of the body may warrant further study.

Internal Decomposition Changes

In regards to the development of decompositional changes in the organs, variation was observed throughout the decay process. Although the transition from to softening to autolysis to liquefaction was relatively stables in some cases, in many others, liquefaction appeared to develop earlier than normal. This process was specifically difficult to pinpoint with accuracy in the non-water outdoor and indoor cases, so much so that it was excluded from the descriptions in that total body scoring system. In terms of the aquatic cases, liquefaction of the brain was sometimes observed to develop as early as a TBS of three and as late as a TBS of five. Given these observations, internal decomposition was not particularly effective in describing the decompositional changes in each phase. As a result, observable external changes, although subject to their own degree of variation, were more heavily relied upon.

Quantitative Observations

Need for Region-Specific Standards

The Role Played by Accurate Total Body Scores as a Key Variable in Time Since Death Estimation Models

In addition to the importance of total body scores which are representative of the decompositional patterns and changes observed in a region, this study has also identified the total body score as a key variable involved in the development of regression equations aimed at estimating time since death. Importantly, the results of the stepwise selection method employed in this study, at both the overall and subset level, correspond with observations made in similar studies such as Bachmann and Simmons (2010). In fact, when discussing the identification of key variables critical to modeling decomposition and estimating time since death, Bachmann and Simmons (2010: 893) found that "TBS was the most valid tool in postmortem interval estimation. All other variables showed weak relationships to decompositional stages, adding little value to PMI estimation."

Remembering back on the results demonstrated in this study, only TBS proved significant across models. All other variables identified as having a large adjusted R^2

value, were shown to not possess a statistically significant effect. Moreover, only TBS was demonstrated to show a similar relationship amongst all depositional contexts when plotted against logADD. Precipitation and insect activity demonstrated the beginnings of a potential relationship, but significant increases in the sample size would be needed to draw out the extent of such trends.

Most importantly, in the analysis of the non-water outdoor PMI subset, a linear dependence was noted by SAS stating, "Selection stopped because all candidate effects for entry are linearly dependent on effects in the model." If one is to think about the root causes of the linear dependence, it becomes clear that total body score plays the most central role. If one thinks about what total body score represents, its importance becomes obvious.

The essence of the total body score is a representation of the observed decompositional changes which have occurred on a body. These changes do not occur in a vacuum. As detailed in great length in previous chapters, multiple variables are involved in accelerating or decelerating the rate of decay. Given the presence of these variables, their effects are played out in the decompositional changes summarized in the total body score. Therefore, TBS captures the joint effects of each variable on decay. Given the tight interrelationships observed between the factors involved in the decay process, the effects of these variables cannot be parceled out, inextricably tied to one another. In total, total body score is a snapshot of the combined roles played by all relevant variables in producing the decompositional changes observed. Thus, by accurately representing the totality of these effects, total body score is the single most important variable involved in modeling decay and estimating time since death.

The critical role played by TBS can be demonstrated even further. If one is to consider the R^2 values between both the overall and non-water outdoor and indoor Delaware River Valley models in comparison to the Megyesi et al. (2005) model when applied to data extracted from this region, a simple process of elimination identifies the key difference. As described above, the Delaware River Valley models explain more of the variation in decomposition, the key question being "why?" All models mentioned above utilize accumulated degree days and total body score descriptions. Accumulated degree days reflect a representation of the effects of both time and temperature, summed as the total of the average temperature per day across a post-mortem period. However, the effects of both time and temperature are standardized in the accumulated degree day total, meaning they play the exact same role and have the exact same effect regardless of the climatic region in which the ADD total is being calculated. As an example, a total of 100 ADD in Delaware is theoretically the exact same as 100 ADD in the North Pole. The body exposed to 100 accumulated degree days in the North Pole has faced the exact same heat-energy units as the corpse deposited in Delaware, as ADD standardizes the effects of both time and temperature.

If accumulated degree days are equal across regions, only one component of the model is left: total body score. Given the fact that when comparing between regions, variables such as temperature, insect activity, carnivore activity, soil type, soil pH, humidity, precipitation, snowfall, cloud covered days, population density, and many more, differ, these effects play out on the decompositional patterns observed. Different variables produce different effects on decomposition across different regions, with the result being a different progression through decomposition. Based on the understanding that total body score represents the joint effects of said variables on the decompositional changes observed, total body score standards representative of the region of interest are the differentiating factor between models.

Unlike the data collection efforts in this study, Megyesi et al. (2005) combine data from 19 different states, spanning multiple regions and climatic environments. In order to score the decomposition in each of those cases, a general total body scoring system was developed. However, the particular patterns and changes included in that system were derived from the study developed by Allison Galloway et al. (1989) to describe the decomposition process in the arid Arizona desert. Although these standards were altered to suit their particular regions of study, it becomes clear where the sources of variation between the Megyesi et al. (2005) model and the Delaware River Valley models occur. Given the higher R^2 values observed in both the overall and non-water outdoor and indoor Delaware River Valley models in comparison to the Megyesi et al. (2005) model, it can be concluded that the total body scoring system developed for the Delaware River Valley is better suited to the region. Taken alone, this particular understanding says it all, essentially highlighting the critical importance of, and need to develop, a total body score system designed to reflect the pattern of decomposition for each particular environment.

Should one need even more evidence of the critical role played by total body scores representative of the region, one need only consider the fact that across each and every comparison made between predicted values utilizing the Delaware River Valley models and the Megyesi et al. (2005) model, the models derived for this area more accurately predicted accumulated degree days in every scenario. Once again, accumulated degree days were standardized between all comparisons, the only difference was the total body scores attributed to each case. Based on the extremely low average differential between predicted and observed ADD values, it can be said that the Delaware River Valley models, especially the non-water outdoor and indoor model, more closely approximates actual accumulated degree days, with the critical difference hinging of the total body score differences between both formulas.

Lastly, as stated by Megyesi et al. (2005: 9) themselves, "Practitioners in other parts of the country are encouraged to use the scoring method outlined here to test our equations with their own data or to generate their own equations in order to better track local environmental and climatic conditions." This study did just that, heeding the call for comparisons and making up a critical component of the analyses conducted. In all, this comparison demonstrated that the Megyesi et al. (2005) formula and total body scoring system were not as applicable to the Delaware River Valley region, as the set of equations and TBS descriptions designed specifically for this area.

In total, based on the greater explanatory potential of the Delaware River Valley models, coupled with the greater accuracy observed, these results demonstrate the utility of models derived for specific areas, and validate the development of region-specific standards. Additionally, these results highlight the fundamental role played by representative total body score descriptions in effectively modeling decomposition and accurately estimating time since death in specific regions.

Against the Development of Universal Decomposition Models

What's more, in case the results of this study, including the development of a set of models which more accurately predicts ADD in the Delaware River Valley, and the subsequent discussion describing the decompositional patterns specific to this area, are not enough to convince the reader regarding the need for decomposition models particular to the region in which decay is taking place, consider the findings of similar studies in other regions of the country.

As summarized perfectly by Sorg and Haglund (2013), during the last quarter century, forensic anthropologists have been seeking to develop universals in regards to modeling decomposition and estimating time since death. However, given the dearth of research in each of the various regions and climates of the United States, investigators have turned to standards and formulas developed in areas outside their own (2013). As a result, time since death estimates have suffered, being applied beyond the scope of the research. In order to address these issues, Sorg and Haglund (2013) specifically call for the development of region-specific decomposition research.

The key problems in the application of formulas as "universal" time since death models are the specific micro-environmental and ecological differences observed between regions. In fact, Wescott et al. (2013: 460) suggest this very point, stating, "The process of decomposition is highly dependent on micro-environmental and regional-ecological conditions, making it difficult to apply time-since death estimations across regions." These particular differences, which manifest themselves in the form of variables displaying differential effects depending on the area, alter the pattern of decomposition. Thus, they do not lend themselves to application across wide geographical expanses.

Additionally, Wescott et al. (2013: 460) go on to further point out that,

> "Ideally, forensic scientists would like to develop a universal model of human decomposition that can be used to estimate time-since-death. However, regional ecological conditions that affect the rate (and possibly stages) of decomposition appear to make this an unrealistic goal. Until forensic scientists truly understand the rates and stages of decomposition, and how they vary from region

> to region, it is unlikely that they will develop accurate universal…models for estimating time-since-death."

In essence, this statement summarizes the critical importance of this study, and emphasizes how sorely decomposition research is needed in the Delaware River Valley region.

Lastly, although this study has consistently compared its results to the Megyesi et al. (2005: 9) research, which has been championed as the gold-standard in the field, Megyesi et al. themselves, demonstrate the importance of regional standards clearly and concisely, stating, "Future research should also concentrate on narrowly defined regions of the United States in order to produce equations that are best tailored to a particular environments." This study did just that, developing a time since death estimation formula, taking into account the presence and interaction of environmental, scene-specific, and depositional factors particular to the Delaware River Valley region. Based on the results demonstrated in this study, as well as the insights derived from decomposition research in varying regions throughout the country, it is hoped that the focus is shifted from the development of universal models to the much more critical need for region-specific formulas.

Model Development

Modernized, Quantitative Approaches to the Development of Decomposition Models: Accumulated Degree Days over Post-Mortem Interval Days

Without a doubt, based on the results demonstrated in this study, any hesitation between the use of accumulated degree days over post-mortem interval days in modeling decay and developing time since death estimation equations should be put to rest. Accumulated degree days proved to explain more of the variation in decomposition across each and every model studied, regardless of depositional context, combined subsets, or overall models. These results are supported by the finds of Megyesi et al. (2005), Heaton et al. (2010), Simmons et al. (2010a; 2010b), Michaud and Gaeten (2011), and Nawrocki and Latham (2013), to name just a few. Given the critical need to address the dearth of quantitative studies in the field, forensic anthropology, taphonomy, and decompositional studies can no longer afford to continue to ignore the utility of accumulated degree days for modelling decomposition.

Unfortunately, despite the fact that the relationship between accumulated degree days and various biological and chemical processes has been known since the 1940s (Davidson 1944), introduced into human decompositional research and forensic anthropology by Vass et al. in 1992, forensic anthropologists have still been very slow in accepting accumulated degree days as the variable to be predicted when estimating time since death (Simmons et al. 2010b). In fact, despite the clear and obvious signs that ADD significantly improves the prediction of time since death, some of the most current publications have still yet to incorporate the principle of accumulated degree days into their research designs or analyses (Magnanti and Williams 2008; Sharanowski et al. 2008; Bunch 2009). Whether the reason for this is based on general reluctance to accept the implications of results generated by its use (Simmons et al. 2010b), or simple ignorance, the time has come where excuses are no longer valid.

As the forensic sciences push to improve their quantitative methods and federal mandates call for statistical backing of estimates of time since death, forensic anthropologists can no longer afford to operate in the past. Suppose a forensic expert testifies in court regarding the estimated post-mortem interval of a case. When the cross-examining attorney questions how such a conclusion was reached, experience and anecdotal evidence alone are no longer valid responses. The principle of accumulated degree days is known and understood in the literature and serious concerns can be reached regarding conclusions which do not incorporate its use. As a result, predictions of time since death must move away from the wide and unnecessarily imprecise estimates resulting from the focus on time and typological approaches, instead concentrating on quantitative reasoning based on the understanding of the key variables and processes at play.

Forensic anthropologists can no longer afford to look these modern methods in the face, while still holding on to the outdated paradigms and modes of operation of the past. It is hoped that by demonstrating the utility of accumulated degree days to the development of decomposition models in a variety of environments, including that of the Delaware River Valley, the discipline will begin to accept this modernized approach to estimating time since death.

Decomposition Model Development: Use of Core over Periphery Processes and Factors

Based on the results of the multitude of analyses conducted, it is clear that both ADD and TBS are the most crucial components of the decomposition model and equation developed in this area. Obviously, accumulated degree days are inextricably tied to the effects of temperature, which is at the heart of the “core” variables championed by Nawrocki and Latham (2013). Total body score on the other hand, combines the joints effects of multiple variables on the decomposition process, including temperature, precipitation, insect activity, and the like, but, also included, are known “periphery” processes and factors such as scavenging, clothing, trauma, and so forth. Therefore, considering these variables and the determination of statistically significant effects on the model produced, one is left to wonder if periphery processes are just as important as core processes in the development of decomposition models and time since death estimation equations.

Based on the experiences drawn from this study, it is certainly much easier to develop models of decay using variables and processes tied to temperature. Temperature data is relatively easy to access, does not require much interpretation, and reduces error. When this is compared to the collection of data regarding periphery variables, it is clear that much more room for subjectivity exists, requiring determinations of the presence or absence of these variables, and in some cases, the degree to which they exist. These determinations are made with very little data, lack of clear-cut evidence, and/or arbitrary indicators.

For example, in the case of the inclusion of insect activity over scavenging activity, insect activity is much easier to model based on the known relationship between insect development and temperature. Forensic entomologists can track the predicted growth rates of insect species based on the collection of historical temperature data in an area. In turn, the effects of insect activity can be correlated to the decompositional changes observed over time. In fact, insect growth has been observed to demonstrate a tighter relationship with the combination of both time and temperature in the form of accumulated degree days, than simple time alone (Carter et al. 2007; Michaud and Moreau 2011).

On the other hand however, scavenging activity has not been determined to be as stringently dependent on any one factor, including ADD. Although temperature and seasonality can play a role in regards to the activity of scavengers, other factors such as population density, attractiveness of remains, accessibility, and so forth, all play a role (Beckhoff and Wells 1980; Haynes 1983; Haglund et al. 1988; Haglund 1997; Klippel and Synstelien 2007). In terms of assessing scavenging over a body, gnaw marks, scoring, pitting, and scratching are the traditional markers of carnivorous activity on bone (Haglund 1997). Bite marks can also be observed on soft tissue. Based on the presence of these indicators, one can conclude the presence and influence of scavenging activity on remains. However, one must also consider cases in which soft tissue has been consumed by insects, hiding evidence of animal manipulation. Moreover, the impact of scavengers on a site is often assessed by the degree of scattering of remains. In many instances, carnivores will not only consume remains, but move them about a site, potentially dragging them great distances during the consumption process. Conversely though, the typical indicators of scattering via scavenging can be mimicked. Consider the loss of skeletal elements through taphonomic processes such as water transport, human activity, extreme weather patterns, and so forth. In turn, usual evidence of scavenging is feigned by these processes, potentially incorrectly noted and included into a dataset.

Along the same vein, consider the assessment of the presence of clothing. In the early post-mortem period, clothing tends to remain on a body. However, after manipulation of the corpse by insects and scavenging, clothing tends to become lost or separated from. Even plant roots have been known to grow in, on, and through remains, removing clothing or altering its position on the body (Rodriguez 1997). What's more, consider the effects of aquatic deposition on remains. The effects of tides, currents, and wave action are known to facilitate the loss of clothing. In total, it is relatively impossible to determine with any degree of certainty at what point the garments were lost, making the development of models utilizing the presence, absence, and degree of clothing cover extremely difficult to piece together.

If one wished to assess the impact of adipocere on decomposition, matters would be complicated even further. Although the “just right” conditions required for adipocere formation are known, the development process is extremely variable and difficult to predict (O’Brien 1997). Furthermore, given the current inability to track the exact water temperatures to which a body has been exposed, how would one be able to model the precise point in time when adipocere formed and began altering the decomposition process? When introduced into the model, this unpredictability would serve to undermine the accuracy of results.

Even the modeling of aquatic decomposition is extremely complicated to map out. Although specifics regarding aquatic contexts will be discussed in subsequent sections, it is important to point out that given the variability observed in aquatic environments, along with the presence of confounding factors and as-yet-unknown variables, as well as the inability to directly determine the extent of the effect of temperature, salinity, and so forth, these issues make the modeling of aquatic decomposition extremely difficult and highly susceptible to variation. This is borne out in the low R^2 values associated with the stratified aquatic models, seen especially when using post-mortem interval days.

Clearly, many periphery variables are too difficult to model with any degree of certainty. However, some processes do exist which not only can be factored into analyses, but must be taken into account should one seek to refine models and more accurately predict time since death. One of those considerations is the development of changes corresponding to mummification. According to Nawrocki and Latham (2013), processes such as freezing, mummification, and so forth are considered peripheral processes. Nonetheless, its development can be captured with relative precision based on a qualitative analysis of decomposition in the region of interest. As it relates specifically to the Delaware River Valley, the effects of mummification were first observed in the advanced decomposition state, with the development of dry and leathery regions corresponding to the late early and moderate stages. By accurately accounting for the presence of mummification, the total body score developed in this region more closely approximates the actual decompositional changes which take place.

The exact same point can be made in regards to skeletonization. Megyesi et al. (2005) seem to almost dismiss the value of the skeletonization stage for providing any insights regarding decomposition. Admittedly, a greater time range is associated with this stage, but this can be said with all stages progressing from the initial point of death outwards. Given the intricacies observed between the first indications of focal exposure of bone, until the development of dry, porous skeletal elements, these subtle differences can be of use to not only determining total body scores, but also more accurately modeling decay.

Thus, although Nawrocki and Latham (2013) are correct in their suggestion that core processes are more amenable and suitable to being modeled, not all periphery variables should be summarily excluded from consideration. Instead, great caution should be taken when considering the accuracy of data collection in regards to any variable included into a model, taking care to ensure their inclusion is based on reliable information.

Time Required to Produce Specific Decompositional Changes by Depositional Context

In the analysis conducted on the total accumulated degree days theoretically required to produce specific total body scores, interesting results were observed between depositional contexts. Initially, outdoor cases were seen to require more accumulated degree days to produce each total body score when compared to indoor cases. In the early phases of decomposition, indoor cases started out requiring the least amount of time to produce each TBS. However, as decomposition progressed into the latter half of the early decomposition period, the relationship between depositional context and the time required to produce higher total body scores, changed. Outdoor cases were shown to require less time to produce these effects compared to indoor cases. This relationship was deemed statistically significant. When considering the root causes behind these differences in the hypothetical "rate of decay" derived in this analysis, the effects of environmental and scene-specific variables are seen to play critical roles.

In regards to cases decomposing in indoor contexts, the relationship observed may be due in part to the joint effects of reduced scavenging activity and a delayed onset of insect access. In fact, when assessing the number of cases observed to show manipulation by scavengers in indoor contexts, only one case demonstrated evidence of scavenging activity. This is in sharp contrast to the 35% of cases exhibiting scavenging activity in outdoor contexts.

Additionally, given the potential difficulty experienced by some insect species in terms of accessing bodies located in enclosed structures, the different composition of the arthropod community may play a role in the decomposition process. Indeed, both Goff (1991) and Anderson (2011) found much greater numbers of individual species outdoors versus indoors. More importantly, Goff (1991) reported findings suggesting some species of insects were restricted to remains discovered indoors, while others were confined to outdoor contexts. Based on the particular pattern observed in the Delaware River Valley, it may very well be the case that initial colonizers in indoor settings, faced with optimal working temperatures, may function to accelerate decomposition at first, but given the decreased species variability and lower overall numbers, eventually lag behind their counterparts in outdoor settings. Overall, these insights not only provide clues as to the differences in the rate of decay between depositional environments, but also highlight the critical need for continued comparative studies between depositional contexts in a number of regions throughout the country.

Therefore, given the greater exposure to insect access, scavenging activity, direct sunlight, and humidity experienced by corpses left to decompose in outdoor contexts, these processes may function to accelerate the decay process in these cases after the initial phases of decomposition. Importantly, given the utility of the joint non-water outdoor and indoor model, the same trend is observed in this model compared to indoor and outdoor cases alone. In fact, the relationship between the results of the non-water outdoor and indoor formula versus those of the indoor formula is also statistically significant. Based on these results, the non-water outdoor and indoor model appears to be a good middle ground between outdoor and indoor contexts, allowing the application of the formula to cases in both environments.

Modeling Decomposition in Non-Water Outdoor Environments

Perhaps of all of the depositional contexts investigated in this study, the non-water outdoor environment typifies the overall message to be derived from this research.

Not only did it explain an extremely high proportion of variation in decomposition, but it made abundantly clear the role played by accumulated degree days and the total body score in modeling decay. One of the most prominent factors involved in producing these results is the critical role of temperature in modeling decomposition, and its interactions with the number of variables known to impact total body score estimates.

Firstly, when considering why these components of the model lined up so well with cases found in non-water outdoor contexts, one need only consider the role played by temperature in the decay process. Clearly, one of the most crucial aspects of data collection, and the formulation of the decomposition model in this study, was the accurate recording of historical temperature data. The National Weather Service Station temperature loggers are designed to precisely record outdoor temperature. However, when it came to determining accumulated degree days in indoor and water contexts, those temperature estimates were invariably imperfect.

Obviously, in regards to indoor environments, the insulating effects of enclosures tend to keep temperatures above that of the outside ambient temperature in cases of cold, and below that in cases of heat. In times of extreme heat, given the failure to produce air circulation, temperatures can even exceed those on the outside, essentially mimicking conditions typically seen in cases of mummification. Given this discrepancy between indoor and outdoor temperatures, it is easy to imagine scenarios in which the bodies deposited in indoor contexts were not exposed to exactly the same accumulated degree days as those left to decompose outside. Perhaps the most accurate readings of actual temperature in indoor environments came from cases in which the heat or air-conditioning was set to a specified temperature. Based on that, rather precise estimates of accumulated degree days could be produced. Unfortunately, these cases were either extremely rare or investigators failed to note the exact temperatures to which the heating or cooling systems were set, instead simply noting that they were on. Therefore, given the inability to capture the exact indoor temperatures, the indoor models were thrown slightly off. Based off of the coefficient of determination in the indoor subset, the values were still relatively high, but it is believed that they would explain an even greater proportion of variation should the exact temperature be known.

In regards to aquatic contexts, as will be discussed in much greater detail below, it was extremely difficult to track down data sources which provided accurate historical temperature data. Once these sources were identified, additional issues surfaced revolving around the transportation of bodies in water, exposing the corpse to various temperature profiles, salinity ranges, and so forth. Given the inability to precisely pinpoint the exact location of a body over time, temperature recordings were surely thrown off. Therefore, when this particular consideration is coupled with additional issues to be discussed below, it is believed that these concerns contributed to the results seen.

Having stated these difficulties, it is important to frame the discussion in regards to temperature's effect on the multitude of variables known to play a role in the decomposition process. As stated above, sufficient heat energy units are needed to drive the biological, chemical, and environmental processes involved in breaking down a corpse. These energy units, represented by accumulated degree days, impact the effects of the various factors which function to alter decomposition. Ultimately, the joint effects of these variables are represented in the total body scores attributed to each case, as it summarizes the decompositional changes which have occurred over a body due to the factors to which it has been exposed. However, if inaccurate accumulated degree day totals are employed, the effects of temperature on those variables will not be accurately represented in the model. Fortunately, in the case of the non-water outdoor subset, it is believed that temperature was more accurately recorded compared to the other contexts analyzed. Given the use of National Weather Service Station data designed specifically to record outdoor temperature, it is believed that outdoor ADD totals more closely approximated the actual temperatures observed on scene. More importantly, the significance of accurate temperature totals is highlighted by the higher proportion of variation explained in the non-water outdoor contexts, compared to the indoor and aquatic environments.

Lastly, the non-water outdoor subset provided one additional revelation. As observed in the PMI day non-water outdoor case analysis, the linear dependence statement produced by SAS based on data points from this subset, helped reveal a very important consideration in regards to modeling decomposition. The variables investigated in this subset are so inextricably related, they cannot be parceled apart. Instead, their effects are represented jointly in the total body score. Given the presence of both TBS and the effects of these variables in the same model, the linear dependence was observed. Based on these results, the central role played by the total body score in modeling decomposition became obvious.

Although the non-water outdoor dataset can certainly be improved, such as by incorporating historical humidity data, subsets of bodies found on varying surfaces, and the like, this particular depositional context has gone a long way towards highlighting the key variables and components necessary in a decompositional model and accurate time since death equation.

Modeling Decomposition in Indoor Environments

In regards to modeling decomposition in indoor environments, the indoor accumulated degree day model did not produce R^2 values as high as those observed in either the overall or non-water outdoor subset. Unlike cases found in aquatic environments, this particular discovery is likely not reflective of the presence of as-yet-unknown variables or confounding factors. Instead, the results from the indoor model are likely related to an inability to determine the exact accumulated degree days to which a corpse has been exposed, especially compared to non-water outdoor cases.

As stated above, given the insulating effects of enclosed structures, corpses found indoors are shielded from direct sun exposure and heat during times of high temperatures, while being protected from the cold during times of low temperatures. In turn, ADD estimates derived from outdoor weather stations are not as precisely applicable to indoor cases as they are outdoors.

Furthermore, given the fact that oftentimes air-conditioners or heating systems are found running during many months of the year, these alterations of outdoor ambient temperature serve to further increase the discrepancies between accumulated degree days calculated from weather station data and the actual temperatures to which a corpse is exposed.

In order to account for these differences between outdoor and indoor temperature, investigators must make more concerted efforts to record actual temperatures within the structures themselves. If heating or cooling systems are observed to have been running during the post-mortem period, the temperature setting should be recorded. Additionally, temperature loggers can be brought to each indoor site in order to accurately capture the actual ADDs to which a body has been exposed.

When a sufficient number of cases have been accurately recorded, they can be re-included into the dataset developed for this study, so as to refine the time since death estimation model and formula derived for cases in these contexts. In this way, the model can continue to be improved with the incorporation of data more closely modeling actual conditions in indoor environments.

Modeling Decomposition in Aquatic Environments

When assessing the stratified analysis conducted on cases left to decompose in aquatic contexts, it was abundantly clear that there was much more to the picture than could be seen. Besides the low R^2 values, especially in regards to the extremely small proportion of variation explained when using post-mortem interval days, and the clear influence of aquatic cases in regards to dragging down the R^2 value in the overall model compared to the non-water outdoor model, the analysis revealed the existence of variables which are either as-yet-unknown or currently too difficult to track back in time with any degree of certainty. When considering potential factors which may play a role in accelerating or decelerating the rate of decay and contributing to the decompositional changes and patterns observed in cases in aquatic contexts, several variables come to mind which lack simple and intuitive methods by which to be collected, instead being wrought with difficulties, especially in regards to retroactive data collection efforts.

Among those difficulties is the inability to track historical data regarding tides, currents, water depth, body transport, variations in temperature and salinity level, time of complete submergence, insect presence, exposure of the body to varying conditions, adipocere development, and much more. When considering these variables, it quickly becomes clear that in order to develop time since death equations specifically designed for aquatic cases, very specialized models, incorporating a number of factors not encountered on land or in indoor environments, are needed.

Unfortunately, even if one was to devise a method by which to collect such data, another more complicated problem arises: how can an investigator determine which of those variables a body was exposed to? For example, there is no mechanism by which to determine the water depth at which a body was suspended, the length of time the corpse spent submerged, or the distance which the body traveled, exposed to various salinity ranges, water pH profiles, and temperature fluctuations. These issues are compounded even further when considering the fact that precise readings of water temperature are difficult to ascertain, especially given the extremely high likelihood of body transport resulting from tides and currents. Given the fact that skeletal elements, such as the skull, have been observed to have travelled both short and long distances, upstream and downstream, it is nearly impossible to pinpoint the exact temperatures to which the corpse, and eventually the skeleton, was exposed. Based on these issues, the claims made by Milligan et al. (2013), who argue that technological methods have not yet been developed which can properly record key aquatic variables, may be true.

To complicate matters even further, evaluations regarding the influence of insect activity on decomposition in aquatic contexts are hampered by the effects of tides, currents, and wave action on corpses. In fact, of the 23 aquatic decomposition cases included in the ADD dataset, only two showed any evidence of insect presence. By simple chance alone it is assumed that this number must be far from the truth, as many more cases should show insect activity at some point during flotation, or else the consumption and break down of tissues would take an extraordinarily long time to occur. Given the fact that the accumulated degree days and total body scores associated with aquatic cases were not observed to differ extensively in comparison to non-water cases, insect must have played a role in the decomposition process. Unfortunately, the true effect of insects on decomposition cannot be captured in aquatic cases, not only throwing off analyses concerning the role played by insects, but directly influencing the development of time since death models and estimates derived from them.

Although many concerns have been proposed in regards to modeling decomposition in aquatic environments, not many solutions exist to address these issues.

In regards to determining insect activity, not much can be done besides carefully analyzing a body. Tissues can be examined for evidence of modification, being careful to distinguish between insect and scavenging activity. Additionally, if no evidence of marine animal involvement is observed, but soft tissues have been consumed, one can evaluate the other regions of the body to determine if the corpse is in the earlier or later stages of decomposition. If the body is in an earlier stage of decay, but still shows evidence of tissue consumption, perhaps this can be an indicator of insect activity.

Furthermore, in regards to more accurately determining the temperature, salinity, pH, tides, currents, and wave action to which a body has been exposed, one lone area of hope lies in studies evaluating the transportation of bodies in water contexts. These types of studies can evaluate the average distance traveled by a body over pre-determined accumulated degree days or post-mortem intervals. Based on those results, the path and average travel distance of a body can be predicted. Once a case is discovered, this model can be applied, estimating the path of the corpses back through time. In fact, preliminary research conducted by D’Alonzo and Bartelink (2013), found that the post-mortem interval was a relatively poor predictor of transport distance, especially in regards to PMIs less than five days in length. The majority of cases were found in the same general area in which deposition took place, although some variation was observed in cases exposed to longer time intervals. If this holds true, this may bode well for aquatic models, as the variables to which a corpse has been exposed to can be tracked and relevant data can be collected. Following this logic, the appropriate historical temperature records, salinity profiles, and pH levels can be applied, leading to a better understanding of the effects played by these variables, and ultimately, a more accurate estimation of time since death.

Cross-Sectional, Retroactive Studies: Comments and Points of Consideration

Cross-sectional, retroactive studies have many benefits. They allow the use of real forensic data, under real forensic conditions. They take into account the interrelationships between factors as they naturally occur, without being manipulated by preventing specific variables to take effect. They permit the use of larger sample sizes and data points,, as cases are easier to obtain when compiling records spanning years into the past. They even allow for more practical research designs, especially in regards to conducting studies on cases in urbanized, densely-populated areas. However, having stated all of these positives, some drawbacks do exist which impact the inferences which can be made from analyses and the examination of relationships and trends amongst variables.

In particular, during the analysis of the effects of variables on the rate of decay, calculated as the average of the total body score divided by either ADD or PMI in each case for each variable examined, some factors showed inverted relationships, counter-intuitive to what one might expect. For example, insect and scavenging activity are well-documented to play important roles in increasing the rate of breakdown of a corpse (Rodriguez and Bass 1985; Haglund et al. 1988; Willey and Snyder 1989; Mann et al. 1990; Haglund 1997; Simmons et al. 2010a; 2010b). However, in the comparison of the average rate of decay between cases showing insect activity versus no insect activity, those cases without insect activity were shown to have a higher mean rate of decay, with this observation also being demonstrated in regards to scavenging. In fact, that difference was determined to be statistically significant. Given the known relationship between insect or scavenging activity and decay, these results are completely contrary to what has been demonstrated in experimental research studies. This of course then raises the question of, "why?" The answer is tied directly to the very nature of cross-sectional, retroactive research.

In studies such as the one conducted here, past cases are compiled and relevant variables are extracted. Evidence of insect activity, scavenging, and so forth are noted and factored into analyses. However, one is never sure of when these particular events took place in relation to the calculated ADD or PMI. Using insect activity as an example, in the non-insect activity group, multiple bodies may have been recovered before insect activity was allowed to develop. Maybe insect activity was precluded in some cases. Even more importantly, perhaps evidence of insect presence was not noted or completely erased by the effects of such variables as tides and currents.

For the insect activity group, the cases could have been “entered” into the study after a longer post-mortem period. Based solely on the principle of chance, corpses showing insect activity could have taken longer to be found. This consideration is made more important when considering the fact that as bodies enter into the later stages of decomposition, more time is required to progress to the next stage. Although cases in the non-insect group may have shown the exact same stage of decomposition as some of those in the insect group, perhaps they were found earlier on in the post-mortem interval, with the insect group failing to progress to a more advanced stage given the amount of time required to do so in the later phases of decomposition. The insect group then appears as if it does not accelerate decomposition to the same degree as the non-insect group because it has remained in that particular stage for longer.

It may even be the case that some bodies were not attractive to insects due to mummification and drying out of the tissues. Given the fact that moist decomposition, which is attractive to insects, occurs earlier on in the process, it may appear as if the presence of insects does not allow the progression to these more advanced mummified stages, in reality tied to temperature, humidity, and aridity levels.

The effects of water on insect activity, especially in regards to tides and currents, have already been discussed. Given the fact that 21 out of 23 aquatic cases showed no evidence of insect activity, this may very well have played a critical role in the results seen. Those cases which did show insect activity could have been in the earlier stages of decomposition by simple chance, while the remaining 21 cases with no evidence of insect presence averaged longer accumulated degree days or post-mortem intervals.

Another critical consideration revolves around the post-mortem interval attributed to each case. As stated above, the known "date last seen" and "date recovered" representing the post-mortem period, may be incorrect in some of these cases. Given the disparity between cases showing insect activity and those not showing any insect presence, these differences may be exacerbated. As a result of these issues, due to the inability to control for when a body is found during the post-mortem period, the mean ADD or PMI for both groups gets pulled in opposite, counter-intuitive directions.

Lastly, and most importantly, it may very well be the case that the further along a body progresses through the decomposition process, the greater chance for the elimination of evidence of insect activity. As bodies breakdown and move into the skeletonization phase, insect presence not only dwindles, given the loss of a food source, but larvae may be consumed by advantageous species, carnivores may consume insects as they scour over the bone remains, and the normal processes of taphonomy and weathering may move evidence of insect activity away from a body or eliminate it altogether. The result of these processes is what appears to be a body in the furthest reaches of decomposition with no evidence of insect activity, when in reality it was the presence of insects which helped move the body to that point in the decomposition process.

Before ending this particular discussion, it is also critically important to point out the reasons behind the results observed in regards to the differences in the rate of decay by depositional context. When analyzing the dataset itself, crucial differences are observed. In particular, when comparing the non-water outdoor cases to indoor cases, the average total body score in the outdoor cases was seen to be nearly twice as large as the mean TBS in the indoor cases. Additionally, the average ADD in the outdoor cases was over three times as large as in the indoor cases, corresponding to the higher TBS values observed in the outdoor samples. Given these critical differences, they essentially handicapped the outdoor dataset, accounting for the slower rate of decay observed. This is not to mention the difficulties which would have arisen in a comparison of outdoor or indoor cases to aquatic cases, given the different total body scoring systems employed between both groups. In all actuality, the only reliable method in which to compare the rate of decay between depositional contexts, would require cases which demonstrated similar total body scores, not only with similar total body scoring systems, but with similar total decomposition. By doing so, an equal comparison would be possible. Unfortunately, based on the inability to control the total body scores in actualistic, retroactive studies, this analysis was handicapped from the start.

Therefore, based on all of these areas of consideration and the plethora of potential scenarios which can serve to misrepresent results, analyses of statistically significant differences in the rate of decay between variables in a study of this type are not particularly informative. Instead, they should merely serve to point out potential relationships or trends which may, or may not, warrant further consideration.

Loss of Statistical Power with Atypical Transformations

Lastly, before moving on to the “Considerations” section of this chapter, one final point should be made regarding the transformations applied to the data in this study compared to the Megyesi et al. (2005) model. In this study, in order to satisfy the normality assumptions required by linear regression analyses, the logarithm of accumulated degree days was taken. This is particularly important to meeting the assumption that the relationship between two variables is linear. Given the non-linear plot initially observed, the logarithm was used to straighten the curve and allow the use of linear regression.

The use of the logarithm is very often seen in the statistical world, serving as one of the most commonly used transformations of data. Indeed, it is often employed given the fact that it is extremely easy to interpret. The main essence behind the transformation is that when increasing $\log_{10}X$ by 1, it is the same as multiplying X by 10. More importantly, transforming data by applying the log is not only simple and straightforward, but it does not function to dramatically alter data points or significantly impact the proportion, *p*.

However, when the model derived in this study is compared to that developed in Megyesi et al. (2005), the latter utilizes not only the logarithm of ADD to straighten the curve, but also the square of TBS. In statistics, squaring data can have a large effect and is not used as frequently as the logarithm. The difference between the use of the logarithm and square is best understood in the context of the ladder of powers or transformations.

In the ladder of transformations, the logarithm is the simplest transformation possible, with a parameter of 0 applied to the data. It sits squarely in the middle of the ladder of powers. As one ascends and descends the ladder, the effect of the transformations on data changes. In terms of square transformations, they stand at the very edge of the spectrum. This has a great deal to do with the effect played by square transformations on data. When applied, large values of X become compressed, while small values of X tend to spread out. This changes the relationship amongst the data points, potentially misrepresenting the relationships which exist.

Moreover, square transformations can function to not only transform the data, but also change its order if applied to negative values. This would obviously significantly misrepresent the actual values of the data points. For example, if a range of values from negative 2 to positive 1 to positive 2 was observed, and the square was applied, the values would be transformed to 1, 4, and 4. Given the fact that a negative value was originally included among the data points, the newly transformed data does not accurately represent the actual relationships in the dataset.

Having considered all of these points, it is important to note that Megyesi et al. (2005) state that the square was applied to the total body score because it normalized the data distribution. However, if it functioned to compress large values and spread out smaller values, one wonders what effect this had on the data and resultant model, impacting its statistical power and the inferences which can be derived from it. One also wonders what role it played in the comparison of models detailed earlier, as the Delaware River Valley model explained a larger proportion of variation. Although TBS is posited to have normalized the dataset, this is one area of consideration to keep in mind when applying the Megyesi et al. (2005) model in regions outside the realm of those investigated in their study.

Considerations

Given the nature of retroactive studies, as well as the focus on particular depositional contexts, some considerations should be taken into account when applying the results demonstrated in this study. Some of those considerations are accepted flaws of studies of this type, while others are merely points to keep in mind when assessing the applicability of the research. In the future, it is hoped that by highlighting these particular issues, these considerations can be studied in greater detail or validated in experimental research studies. Given the impracticality of expecting a study to cover the entire realm of potential issues and account for every flaw in design, as is the nature of scientific inquiry, continuous attempts must be made to refine, improve, and fill in gaps where necessary.

Accumulated Degree Day Prediction Utilizing the Delaware River Valley Formula

Before moving on to a discussion of the main points to take into consideration, a brief mention of the use of the time since death formulas developed for the Delaware River Valley is warranted.

As mentioned above, after determining the total body score, one need only plug the score into the appropriate formula and derive an estimate of accumulated degree days. However, it should be noted that when using the overall time since death estimation model, for those cases recovered from aquatic environments, the total body score must be weighted onto a 42 point scale. From there, in such cases, the nearest National Data Buoy Center to the recovery site should be accessed in order to collect historical temperature data. In regards to non-water outdoor and indoor cases, the nearest National Weather Service Station to the recovery site should be accessed for historical temperature records. The average temperature per day, calculated by taking the minimum and maximum temperatures each day and dividing by two, should be determined. This process should be repeated for each day from the date of recovery of the body, back until the estimated accumulated degree day threshold is met. Based on the number of days required to meet that threshold, one is provided with the time since death interval in days.

Lastly, in order to facilitate the attribution of 95% confidence and prediction intervals, they were forecasted for both the overall and the joint outdoor and indoor equations utilizing all possible total body scores (see Tables 43 through 46). Therefore, after calculating the predicted accumulated degree days, the confidence and prediction intervals can be attributed as appropriate.

Delaware River Valley Model Selection

Based on the totality of the results described in the previous chapter, several time since death estimation equations were able to be developed for use in cases found in the Delaware River Valley region. A specific discussion of the conditions to which these models are applicable can be found in subsequent sections. The foundation of these models is built on the standardization of both time and temperature in the form of accumulated degree days, and the accurate representation of decomposition in the area in the form of a total body scoring system. TBS is utilized as the key variable involved in not only quantifying the observed decompositional changes, but summing the effects of the various factors involved in the decomposition process.

As a result, two key time since death equations have been able to be developed from the data: an overall model including cases from all three depositional contexts examined, and a non-water outdoor and indoor model. In terms of raw numbers, the non-water outdoor and indoor model explains more of the variation in decomposition and more closely approximates actual observed ADD values when used for prediction. Thus, it is more mathematically accurate. It also corresponds with the total body score system developed specifically for non-water outdoor and indoor contexts, not requiring the weighting of aquatic cases incorporated into the model. Given these considerations, it would make sense to apply this specific model to cases found in these environments.

However, one important point to keep in mind concerns the sample size from which this model is derived. As mentioned above, non-water outdoor and indoor cases accounted for 57 cases in this dataset. If one is weary about using a model derived from a dataset of this size, the overall model can be used which includes 80 total cases, one need only remember to accurately weigh aquatic cases onto the same total body score scale used for the non-water outdoor and indoor subsets.

Despite these points, it is also important to note that aquatic cases in and of themselves may be too difficult to model. They may introduce error into the overall sample, as well as the existence of confounding factors and as-yet-unknown variables, thereby lowering the explanatory value of the model. Given the low R^2 values attributed to the aquatic subsets in this study, especially when utilizing post-mortem interval days, the use of the aquatic subset alone is discouraged.

For these reasons, as well as those stated above, it is recommended that the non-water outdoor and indoor model be used for cases which fall into these categories. The overall model can be used for aquatic cases, but the drawbacks should be understood. In the future, the overall model can serve as a springboard from which to model more cases. By adding data to bolster the distribution of cases in each of the depositional contexts included, this will foster a more representative model.

Model Application

Application of the Delaware River Valley Model to Uncommon Situations or Contexts

As described above, the equation derived from this study was developed utilizing cases stemming from non-water outdoor, indoor, and aquatic contexts. The cases in these contexts were not exposed to unusual circumstances or unique situations. Aquatic cases were found in rivers, bays, canals, and the ocean. Non-water outdoor cases were found either on the soil surface, hanging, or on concrete. Indoor cases were found in enclosed environments such as houses, trailers, and apartments. Given the "normal" circumstances to which these bodies were exposed, coupled with the fact that they were used to develop a decomposition model, it is unknown how the equation will fair in uncommon or unusual contexts. Therefore, caution should be used when the model is applied to cases outside the range of those contexts studied.

As mentioned earlier, no saponified, charred, dismembered, buried, or mixed-context cases were included in the analysis. In regards to saponification, it has been well-established that adipocere slows decomposition and preserves remains. In such cases, bodies can become encased in saponified tissue, preventing aerobic respiration, insect activity, and the breakdown of tissues. This is in stark contrast to the typical processes observed under normal situations. Should the equation be applied to such cases, it is highly likely that an underestimation of the actual time of death will result.

In another example of the potential dangers concerning the application of decompositional standards to cases in non-typical conditions, consider the results of Gruenthal et al.'s (2012) study on charred remains. While the decomposition rate was not statistically different between charred versus non-charred groups, the charred bodies initially showed a more advanced pattern of decomposition. Additionally, differences were observed in the rate of decomposition between different regions of the body depending on the level of charring. In those areas exposed to higher charring, decomposition progressed faster. In fact, the researchers posit that arthropods may be more attracted to charred remains, given the possibility that more fluids and scents are given off in those bodies.

Moreover, in non-charred cases, the traditional pattern of decomposition was observed, beginning first in the head, progressing to the neck and torso, and finishing with the limbs. However, in the charred group, the torsos of all the cases began to decompose first, followed by the neck, and then head. When this fact is coupled with the significantly different decomposition rates in different regions of the body, and the initial rapid progression of decomposition in charred remains, charred bodies may demonstrate decompositional changes typically seen at specific times in the decomposition process, but actually not be as far along in the process as expected. Given these considerations, Gruenthal et al. (2012) conclude that investigators should be cautious in the use of predictive equations in these situations, instead advocating for the use of their Charred Body Scale, if circumstantial evidence at the scene indicates fire modification.

What's more, it is important to note that no dismembered bodies were considered in this analysis. During dismemberment, body parts may be exposed to varying conditions, the typical bloating process may be altered, and the spread of bacteria and gas may be disturbed. When this consideration is coupled with the inability to confirm the state of the remaining regions of the body in these situations, this study advises against applying the time since death estimation models developed here to those cases in which only a handful of remains have been recovered.

Additionally, although cases deposited on soil surfaces were examined in this study, no cases in buried contexts were observed. Given the hypothesized differences in the rate of decomposition, said to be eight times slower in buried bodies (Maples and Browning 1994), the time since death equation may not be of much use. More specifically, given the insulation and protection of remains from temperature fluctuations in burial environments (Rodriguez and Bass 1985), the calculation of accumulated degree days from ambient temperature may not be applicable. Furthermore, due to the inability of insects or scavengers to access remains buried more than a foot below the surface (1985), the pattern of decompositional changes may not mirror those reflected in the total body score descriptions developed for non-water outdoor and indoor depositions. When taken together, these sources of error should be considered strongly.

Furthermore, it should be noted that mixed-context cases should be approached with caution. When considering the decompositional changes observed on a body found on the shoreline, it cannot be said with 100% certainty, that the individual spent the entire post-mortem period on land. More than likely in that scenario, the corpse washed ashore. Given the exposure to multiple depositional contexts, and thus varying temperatures and exposure to insect activity, decomposition may not have progressed to the extent expected in a case deposited on land. One can even argue that cases found in the water in tidal systems cannot be said with 100% certainty to have been submerged for the entire post-mortem submersion interval, as during times of high tide or flooding, the corpse may have been left to decompose in the open air, before being re-suspended in water

(Heaton et al. 2010). In those situations however, it is safer to assume typical aquatic decomposition than in those cases found along the shoreline. Regardless, if it is suspected that a corpse has been exposed to both contexts for a prolonged period of time, time since death estimates must be taken with a grain of salt.

Before ending the discussion, one last important point of consideration exists. Both the cause of death and/or conditions at the time of death can contribute to differential rates of decomposition and atypical decompositional patterns. In particular, it has been observed that accelerated decomposition can result from a variety of conditions present at death. Specifically, high air temperatures, hyperglycemia, and infections such as sepsis, are all situations which promote rapid bacterial growth (Zhou and Byard 2011). Given the ability of warm environments to increase internal core temperatures such as in cases where bodies are found lying next to heaters, under electrical blankets, or in individuals with fevers, in saunas, or under heated water, bacterial growth becomes accelerated, resulting in an increase in the rate of decomposition (2011).

Similarly, it has been observed that regional putrefaction can result from the exposure of bodies to different microenvironments. This particular observation was seen in Fernando et al.'s (2013) case study of an unusual pattern of decomposition associated with suicidal electrocution in a bath. Due to the electrical impulses emanating from two hairdryers placed in the tub, the bath water became heated, leading to marked putrefaction and softening of those body parts immersed under water (2013). Those aspects of the body not under water, the back and feet, remained preserved.

In total, conditions leading to increased heat exposure at the time of death can serve to produce decompositional changes misaligned with their typical time of appearance. Under these circumstances, careful decisions must be made to avoid incorrectly estimating time since death.

Therefore, based on the particular examples provided, as well as the infinite number of atypical situations possible, caution must be taken in the application of the Delaware River Valley model to atypical contexts.

Application of the Delaware River Valley Model to Cases between the Lowest and Highest Total Body Scores

Building on the previous section, the use of the Delaware River Valley model should be approached with caution when applied to cases between the lowest and highest three total body scores.

In the early post-mortem period, more accurate methods exist with which to estimate time since death. Given the error range associated with time since death estimates utilizing regression equations, the 95% confidence interval limits will likely be below zero, or too low, to be of real value in these early stages. If one can confidently employ the use of entomological standards, temperature nanograms, or any other method which incorporates the joint effects of both time and temperature into its model, those methods should be used when total body scores are assessed to be low. In cases at or below a total body score of 10, the lower confidence interval limit may even be set at 0 ADD. In this way, the time since death estimate can be sufficiently narrow to be of use to medico-legal investigations.

Caution should also be taken in regards to the use of the model in cases above a total body score of 39. These cases make-up the most extreme limits of the total body score. In fact, they are included in the scoring system so that investigators are aware that the corpse is in the furthest stage possible, alerting them to be cautious in the application of the model to that specific case. The particular reasoning behind this warning revolves around two main reasons.

The first concerns the fact that no cases with a total body score above 39 were included in the dataset, as these cases were identified as outliers, skewing the data and the average derived from it. Therefore, there is no direct understanding of the relationship between total body score and accumulated degree days in those upper limits.

The second reason is more intuitive in nature. Given the fact that scores above 39 represent cases in the furthest reaches of decomposition, there technically is no upper limit on the time since death estimate which can be derived from the equation. A body in that state can be one year post-mortem, 100 years post-mortem, or any number of years post-mortem, up to infinity. When this fact is coupled with the lack of cases in this range included in the dataset, extreme caution should be taken with this upper bound. Should the equation be employed under such circumstances, the average should be stated, along with the confidence interval and an appropriate disclaimer.

Lastly, given the nature of aquatic deposition, fluvial transport of body parts and bones is a common complication in the recovery of remains. At times, only a single bone or a handful of bones are recovered, completely devoid of soft tissue. Unfortunately, one does not know how long the bone has been separated from the main cluster of skeletal elements, how long it has been in the final phase of decomposition, or what the state is of the remaining parts of the body. Given this fact, strong caution should be taken in assuming all other elements of the corpse are in the final stages of decay, and estimates of time since death on single bone recoveries, utilizing the standards and formulas developed in this study, should not be heavily relied upon.

Calculation of Accumulated Degree Days

Collecting Historical Temperature Records

As mentioned in the methods section, accumulated degree days are calculated by summing the average minimum and maximum temperatures per day across a post-mortem interval period. In order to do so, historical data from the nearest National Weather Service Station was accessed for each case. However, this does not mean that the nearest station always had data available. In some instances, the next closest station needed to be consulted. Moreover, just because the nearest weather station is being used, it doesn't necessarily mean that the temperature in that location is the same as that observed on scene. As first pointed out by Catts (1992), there may be significant differences between temperatures on site and those recorded at the weather station, especially if the site is in an unusual location. Given the potential discrepancies, this may have implications for the accuracy of ADD totals. Unfortunately, given the lack of access to a decompositional research facility in the Delaware River Valley area, temperature loggers could not be employed to accurately track temperatures on site. Given the inability to control the collection of temperature data or the proximity of National Weather Service Stations to scenes, this was an accepted part of the study.

However, it is important to state that some potential solutions have been proposed. In a study conducted by Archer (2004), it is reported that correction factors are needed in order to improve the accuracy of temperature records derived from weather stations and applied to sites. In particular, Archer (2004) argues for the use of a temperature logger on site where the body was found, in order to derive a regression equation that describes the relationship between measurements taken at both locations. In turn, the equation could then be used to "correct" temperature records as they apply to the site.

Although this particular idea has its benefits, some drawbacks do exist. In particular, it is important to note that this "correction" was not effective 100% of the time, actually having the opposite effect on a few occasions. In addition, given the ability of the circumstances of the case to impact temperatures and estimates, such as location, seasonality, dramatic fluctuations, and so forth, "generous" error margins are called for to account for this "highly variable" relationship (2004). Lastly, given the ability of maggots to partially regulate their temperatures by forming masses to increase temperature and disbanding to decrease temperature, it is extremely difficult to precisely estimate the exact conditions to which the body was exposed. This will be discussed in more detail in the next section.

Nevertheless, regardless of method, there are clearly a number of issues involved in applying weather station data to a site. However, developing a "correction" factor for each individual case is unrealistic, at least as it pertains to this study. For the purposes of this research in particular, it would have been impossible to develop a regression equation describing the relationship for each site and nearest weather station, especially considering the sample size, need to buy multiple temperature loggers, and the immense amount of time required to accomplish this task. This particular method is much better suited to experimental research studies with one or two cases in varying locations in an area, which was the primary focus of Archer's (2004) study.

Most importantly however, are the results of a study by Dourel et al. (2010) which argue that there is an “uncertain benefit” in regards to the use of corrected weather station data. In fact Dourel et al. (2010: 1) explicitly state, “The forensic entomologist should be cautious when using this correction model.” When this warning is coupled with the fact that correction factors are subject to their own errors and flaws, the risk/benefit relationship between the use and non-use of correction factors starts to tilt in the favor of leaving data as is. Therefore, although the *potential* concerns regarding this particular methodological approach are understood, this study accepted them as an unavoidable aspect of this type of research project. Perhaps upon application of the time since death formula derived from this research to medico-legal investigations, individual cases can develop correction factors on their own.

Before ending the discussion, it is important to note that the particular concerns in regards to historical temperature data are exacerbated in cases involving aquatic decomposition, especially based on the experiences of the author in this study. Under these circumstances, not only was historical water temperature data harder to come by, but it was impossible to track the location of bodies from the point of submersion until recovery, unless the point of entry was known. Given the fact that bodies could have been floating in areas with different temperatures compared to the location in which the body was ultimately recovered, this is another source of difficulty involved in modeling decomposition in aquatic contexts and, as a result, accurately estimating time since death under these circumstances. Estimates of time since death in outdoor and indoor contexts are aided by knowing the exact location of initial deposition in most situations, aquatic cases are not provided with such a convenience. In fact, the lower R^2 values observed in the aquatic subset, compared to the non-water outdoor and indoor subsets, may be a direct reflection of this uncertainty. Unfortunately, no obvious solution to this issue is apparent in regards to data accumulation in retroactive research studies. Even correction factors would be relatively useless as the travel path of the body cannot be pinpointed with any accuracy. In these situations, the only option available is to access historical temperature data in the area in which the body is recovered.

In total, it is important that when applied under actual forensic circumstances, investigators do their due diligence in scoping out the closest station, as well as the exact site location in relation to such stations. Should historical temperature records not be available, all efforts should be made to ensure the next-closest station is consulted. Although this may require a little extra effort, the increased accuracy of accumulated degree day totals is more than worth the trouble.

Accumulated Degrees Days and the Maggot Mass Effect

One very interesting point to consider in regards to the calculation of the total accumulated degree days to which a corpse has been exposed, stems from an observation made by Simmons et al. (2010b: 891) stating,

> "Although the calculation of postmortem interval (PMI) using ADD of ambient temperature has been the norm, the results of this experiment call that practice into question, as the intra-abdominal maggot mass temperatures are minimally 5 degrees C above that of ambient. It has certainly been shown both experimentally and anecdotally that maggot masses of a certain size can survive refrigeration and more importantly not become delayed in their development because of the fact that the maggot mass has its own higher temperature. However, this knowledge has yet to be applied to decomposition rate calculations. More research on maggot mass thermodynamics is needed to fully appreciate their influence on decomposition with respect to ambient temperature."

Considering the fact that lower development thresholds have been developed based on the assumption that insect activity is halted below the freezing point, which has then been translated over to the development of time since death equations by recording all temperatures below the freezing point as zero degrees Celsius, the maggot mass effect may be an important consideration in regards to fine-tuning estimates and models. The most obvious solution would involve developing a correction factor for ambient temperature, taking into account the effect of maggot masses on accumulated degree days.

However, there is a complication involved in this regard. One cannot simply lower the developmental threshold by five degrees Celsius and end the discussion there. Unfortunately, the question arises regarding how the application of such a correction factor in cases where insect activity was reduced, impacts the accuracy of ADD totals. Given the fact that not all corpses are exposed to the same degree of insect activity or the same size of maggot masses, careful consideration must be given to accurately calculating their effect on temperature across cases. Furthermore, another source of concern arises: in cases where the body has been deposited in an environment displaying temperatures below the freezing point, before insects have had the opportunity to colonize a body and develop a mass, the same maggot mass effect cannot be attributed to it compared to cases where the mass was already present before temperatures dropped below freezing.

Despite these concerns, not many answers are available to combat these issues. Many more studies need to be conducted in order to address these questions and develop solutions applicable to the variety of conceivable possibilities at a site. A good starting point involves developing a correction factor accounting for the average effect of a maggot mass and applying it in situations in which definite insect activity is known. In regards to the realm of possibilities outside of those scenarios, further research is needed.

Use of Retroactive, Actualistic Studies

Finally, in addition to the discussion raised in regards to cross-sectional research studies, as stated by Komar (1998), one of the accepted flaws of a retroactive, actualistic study using Medical Examiner records is the fact that often the only data available in regards to the post-mortem interval is the "date last seen" and the "date recovered." The actual date of death is very difficult to ascertain. If medico-legal investigators are not rigorous in their post-identification efforts aimed at determining the actual date of death of an individual, or if the individual was not in regular contact with people, the "date recovered" and the actual date of death may differ. This particular point is often exacerbated in cases involving advanced decomposition and skeletonization, especially considering the fact that often times individuals will be found earlier on in the post-mortem interval when they are reported missing. For those individuals whose disappearance does not raise any red flags or is not reported to law enforcement, the "date last seen" is often unreliable as a marker of "date of death." Since it is very rare that a person passes away immediately after being last seen, overestimations of PMI are therefore likely. Given the retroactive nature of this research study, this is a potential flaw to consider.

However, much like the flaws of experimental studies highlighted in previous chapters, this particular inability to track the exact post-mortem interval is understood to be an accepted part of studies of this nature. Given the fact that decomposition research facilities in the area are lacking, coupled with attempts to utilize cases exposed to real-life conditions, there is no better option by which to approach this type of research. Trade-offs are an unfortunate reality in studies of this type and this particular trade-off is difficult to avoid. However, as will be discussed below, it is hoped that the actualistic results derived from this study can be validated and refined by future experimental studies, limiting the impact of flaws in both types of research designs.

Future Studies

Developing Temperature Correction Factors

As stated above, issues exist regarding accurately calculating accumulated degree days based on historical temperature data derived from the nearest National Weather Service Station. Although the recommendations laid out by Archer (2004) were impractical for the purposes of this study, they may be factored into future iterations of the Delaware River Valley time since death estimation model if correction factors are able to be experimentally derived from the area. Of course, that would be a research study in and of itself, complete with its own experimentally validated evaluation of temperature differences in multiple locations throughout the region, utilizing all, or nearly all, of the weather service stations available. A determination would need to be made if a general correction factor needs to be developed, based primarily on the distance away from a weather station, or if correction factors would be needed for each specific weather station, given differences in temperature and climate between various areas. In the latter case, factors could be developed for coastal, urban, mountainous, open-land regions, and so forth.

Additionally, based on the claims pointed out by researchers such as Dourel et al. (2010) the benefits of using such a correction factor would need to be spelled out. The high degree of variability inherent to correction factors, as well as their associated errors and potential for miscalculation would need to be accounted for and diminished. Given the current lack of research in the Delaware River Valley area, significant strides would need to be made before they were included in the model.

However, although the development of correction factors for the number of cases in this dataset was impractical, they would be welcomed in future versions of the Delaware River Valley time since death estimation model if they were experimentally validated in this region and could be supported statistically.

Incorporation of an Accumulated Humidity Day Model

The development of the principle of accumulated degree days, and its application to decomposition research has had a tremendous impact in regards to standardizing the effects of time and temperature, and allowing the comparison of studies across regions. However, in addition to the critical role played by temperature in modeling decomposition, the closely related phenomena of humidity should also be evaluated in regards to its relationship to decay.

In fact, humidity has already been demonstrated to play a central role in facilitating decomposition and providing a favorable habitat for microbial decomposers and arthropods to breakdown tissues. Humidity is correlated with an acceleration of the rate of decay, due primarily to the increase in bacterial action and fly and maggot activity (Mann et al. 1990). Besides providing more favorable conditions for insects to operate under, humidity also slows the drying of soft tissue, allowing for ease of consumption by insects. If flies are provided with proper conditions to oviposit and larvae are capable of feeding, corpses will break down fairly quickly. This is in sharp contrast to the effects played by aridity on remains, which rapidly dehydrates skin and internal organs, creating a natural buffer against insects and other organisms (1990). Given the drying out of tissues under these conditions, these cases may show very little destruction by insects due to the need for fly eggs to be deposited in areas of moisture and protected from direct solar radiation (1990).

Therefore, based on the obvious importance of humidity to driving the decomposition process, several researchers have argued for its inclusion into decomposition models and formulas estimating time since death. In fact, at the 2013 American Academy of Forensic Sciences Annual Meeting alone, David Carter, Marcella Sorg, and William Haglund, all called for the incorporation of accumulated humidity days, or AHD, into decomposition research.

Given the clear relationship between decomposition and humidity, it would appear as if the inclusion of humidity levels over a specified time interval would already have been factored into quantitative decomposition models. However, at least in regards to the experience of this author, historical humidity data is hard to come by. Based on a search of the various federal government databases related to the collection of weather records, including those of the National Oceanic and Atmospheric Administration, no data records regarding relative humidity levels could be located. If they were available, they would have been factored into this study in some capacity, most likely by combining its effects with accumulated degree days in some manner. Unfortunately, this was not the case, potentially accounting for the failure to incorporate measures of AHD in quantitative research studies.

However, should a method be devised to collect this data in actualistic studies, or should the federal government provide easier access to historical humidity records, without a doubt, AHD will begin being incorporated into decomposition studies. Given the critical role played by humidity on decomposition, its inclusion is certainly warranted, functioning to only increase the accuracy of time since death estimation models, regardless of region.

Increasing the Statistical Power of Analysis through Larger Sample Sizes

Although this study sought out to develop as representative of a sample size as possible, including all cases which met the criteria laid out in the research design, larger sample sizes are always of benefit to models and regression analyses. Larger sample sizes hold greater statistical power, allowing stronger inferences and more confident conclusions regarding a model's potential to accurately represent occurrences under actual conditions. Given the value of larger sample sets, this study will continue to attempt to incorporate new cases into the fold, whether through continued data collection efforts at the Delaware Office of the Chief Medical Examiner, or through the inclusion of cases from additional Medical Examiner offices in the region.

By increasing the sample size from which to draw conclusions, more determinations can be made regarding potential relationships which exist amongst various factors. For example, given the small sample sizes in the subsets in this analysis, some variables, which may actually demonstrate a statistically significant relationship with decomposition, may have gone unnoticed because their effects were not able to be drawn out. With a larger sample size, the effects of such factors as soil type, soil pH, dirty versus clean houses, and so forth, may be better represented. The same principle applies to the trends demonstrated in the continuous plots. Relationships may exist between logADD and precipitation, insect activity, and so forth, but more samples are needed to come up with more definitive conclusions.

Additionally, it is always helpful to increase the sample size of a dataset with cases which are harder to come by. Skeletonized cases are not frequently encountered, given the fact that corpses are more likely to have been discovered before that stage of decomposition is reached. By continuing to incorporate more examples of such cases in the dataset, the standard error in regards to these types of cases will be decreased, allowing for more confident determinations of time since death under these circumstances. The models derived from such analyses will also be more representative across all stages, strengthening the ability of the model to accurately predict time since death.

Lastly, should more and more cases be incorporated into the dataset as time goes on, the differences between the Megyesi et al. (2005) and the Delaware River Valley models will likely be demonstrated to be statistically significant. Although the current analysis demonstrates the Delaware River Valley model to be more accurate, it is always better to have strong statistical backing to support such statements. If more cases can be inputted into the dataset as time goes on, or if additional Medical Examiner offices in the area are able to contribute their cases to the cause, these differences can be pulled further apart.

Obviously, retroactive studies are hampered by the fact that they are at the mercy of the cases available, but as new cases come in, the dataset can continue to grow, refining the time since death estimation model as time goes on.

Confirming the Observations Made in Actualistic Studies with Experimental Research

Although the results presented here are believed to truly represent the patterns and relationships observed under actual forensic conditions, experimental research studies should be developed which serve to test these results. Experimental studies exhibit greater control over factors when compared to retroactive and actualistic studies, zeroing in on those variables of interest to the research. It can control for confounding factors and get at the heart of the main variables involved in the decomposition process. Unfortunately for the Delaware River Valley, no experimental research sites exist. Universities do not have separate forensic anthropology programs, and decomposition research is not a priority.

Clearly, given the importance of time since death estimates to both unknown and missing persons cases, as well as the development of a list of suspects and a general understanding of the events surrounding a case, greater importance should be placed on understanding the decomposition process in the region. Should efforts be made to do so, both experimental research studies and the results of this actualistic analysis, can serve to inform each other, improving models and addressing issues with both types of research. In the end, the result will be a more refined and accurate time since death estimation model by which to solve cases and identify remains.

Standardizing Data Collection Efforts in the Medico-Legal and Research Communities

One of the observations made during the collection of data dealt with the information contained in medico-legal investigation reports. The intended purpose of such reports is to detail the location of the find, background on the case, particulars about the scene, description of the body and observed variables in and around the corpse, identification efforts, results of supplemental examinations, and so forth. However, it was often found that inconsistencies were observed between reports. Some investigators recorded information pertaining to particular variables. Others provided greater details than others. Occasionally, some cases were left without updates or conclusions. Unfortunately, this made data collection efforts even more difficult, lowering the sample size by forcing the exclusion of case records with missing information or poor descriptions.

One particular area of concern revolved around the description of cases found in aquatic environments. Given the difficulties already apparent in regards to modeling decomposition in water contexts, further complications, especially those which can be avoided, are certainly not needed. Unfortunately, these observations appear to not be specific to Delaware or even to medico-legal reports. As per Hobischak and Anderson (2002), better descriptions are needed on the part of not just forensic investigators, but also pathologists and coroners, in regards to water death investigations. In fact, they stated that descriptions were so poor that comparisons of research studies to actual medico-legal forensic cases were limited to just 23% of the 65 possible freshwater cases in their dataset. Of that percentage, only one single case mentioned the presence of invertebrates found on the body, with four mentioning scavenging activity.

Furthermore, although similarities were seen in many of the early decompositional characteristics, the classifications in the coroner's reports were so vague they were of little value to estimating the post-mortem submersion interval. They go on to note that given the vagueness of the descriptions, it almost appeared as if the longer a corpse was submerged, the vaguer the description in the coroner's files were. Given the inverse relationship between the longer one has been deceased for and the accuracy of time since death estimates, these descriptions should be the most detailed of all. This consideration is also coupled with the fact that given the need to develop more specific, and detailed descriptions of decomposition for the development of total body scores, broad and non-specific descriptions are of no value to either research studies or medico-legal investigations.

As it applies to this study, in several instances, cases needed to be excluded from consideration in the dataset given a general lack of information, failure to capture data on key variables, or poor descriptions. Scavenging activity was not described in particular detail. Never was there a mention of the salinity profile of the body of water in which the corpse was found. In only very few instances were tides or currents described. Most importantly however, water temperature data was never collected.

Unfortunately, the issues regarding data collection did not stop with aquatic contexts. In nearly every case, indoor temperature information was lacking. Not only was there no data provided in regards to the ambient indoor temperature, but in those cases where the heat or air-conditioning was on, only some investigator reports stated the temperature to which these systems were set. Given the critical role played by accumulated degree days in regards to providing the heat energy units which drive biological and chemical processes, this particular omission was of the upmost importance. What's more concerning is the fact that recording data in regards to indoor temperature is not particularly difficult, especially when digitized on a heating or cooling panel.

Lastly, despite the known correlation between temperature and decomposition, temperature was rarely noted in outdoor contexts. Occasionally, the overall weather trend over the last few weeks was mentioned, but no specifics were given. Nevertheless, closely related variables such as humidity, cloud cover, and precipitation were rarely, if ever, discussed, unless having directly impacted the scattering of remains or movement of the body. Information pertaining to canopy cover and shade was also frequently missing, requiring consultation of scene photographs to make judgments regarding the degree of sun exposure. The degree of scavenging activity was also documented to differing degrees. Some investigators stated the exact GPS coordinates of bones recovered after scattering, while others simply stated that they were not recovered with the body. For those cases recovered on the soil surface, the soil type and pH was never revealed, simply mentioning the fact that they were found in forested environments or open fields.

Fortunately, all of these concerns are fixable. Besides putting forth a greater effort in regards to more detailed descriptions of the body and the forensic scene, as well as emphasizing the need for the collection of as much information as possible, the standardization of data collection in regards to medico-legal and autopsy reports can go a long way to resolving these issues. In fact, during the author's time at the Delaware Office of the Chief Medical Examiner, a list of key variables to collect was created, including a description of why these factors were important. The list was received well as investigators understood the particular focus of the study. By improving the collection of data in Medical Examiner offices around the country, standardization will also function to improve total body score determinations for each case, as investigators are made aware of the particular descriptions needed to form a better understanding of the decompositional stage which a body is in.

What's more, this focus on the standardization of data collection across the medico-legal community is also of importance to decomposition research efforts. In a broader sense, if, as proposed by Sorg and Haglund (2013), a systematic set of methods are proposed which foster comparison across regions, the collection of data not only in the medico-legal community, but for the purposes of research, may be improved as well. Given the recent growth of “body farms” and experimental decompositional research facilities across the country, in order to evaluate the research discoveries found from region to region, parameters must be established to try and piece together information pertaining to ecological variables and datasets (2013). Minimally, this includes calculations of ADD, AHD, and TBS in all such decomposition studies across regions (2013).

As it relates to scene investigation on the part of medico-legal investigators, Sorg and Haglund (2013) call for the standardized collection of data including: 1) recording heat at the scene, 2) calibrating scene data with weather station data, 3) collecting data pertaining to solar access, such as canopy cover, 4) noting local scavenger patterns and markers of activity, 5) describing seasonal patterns, 6) noting differences in the timing of metamorphosis of local terrestrial arthropod species and marine amphipods, and 7) noting variation in local plant distribution and biology. These recommendations are surely a good start, beginning the conversation regarding the standardization of data across regions and research studies. As stated by Page et al. (2011a; 2011b), the standardization of methods is not only important to ensuring the equal and consistent collection of data for use in medico-legal cases, but to also demonstrate the validity of conclusions derived from research conducted utilizing a standard set of methods in the discipline.

Thus, by standardizing data collection efforts across studies, and encouraging the evaluation of data pertaining to certain key variables, such standardization efforts will foster a greater understanding of the variables which impact decay across regions and allow for the development of more refined decomposition models. It will also facilitate the comparison of research data between studies, potentially leading to the discovery of important relationships and trends. All in all, these issues of standardization are more than capable of being addressed, and can go a long way towards further improving the medico-legal and research community's understanding of decomposition.

Disseminating Results to the Medico-Legal Community

This study is only as good as its application in the field. Should the medico-legal community not be aware of its existence or should they employ it incorrectly, it is not only relatively useless, but it can have far-reaching implications in terms of criminal investigations. Therefore, in order to disseminate the results of this study to all relevant persons, ensure the appropriate use of the equation, and spell out the limits of the study, several steps will be taken.

Firstly, in order to make all relevant investigators, forensic pathologists, Medical Examiners, and medico-legal personnel aware of the findings of this study and the availability of a time since death estimation formula specifically derived for the region, the equation will be circulated to the various investigative and forensic agencies in southeastern PA, NJ, and DE.

Next, a lecture series, involving training in regards to the use of the formula at scenes and the limits of its application, will be established to facilitate the use of the equation in medico-legal settings. Given the author's strong ties to the New Jersey State Police, Delaware Office of the Chief Medical Examiner, as well as various local police departments and Medical Examiner's offices throughout the region, this should greatly facilitate the process.

Lastly, the results of the study will be made available to all interested parties, serving as a model for future studies assessing regional decomposition and to aid in the continual development of improved quantitative methods for determining time since death. Should there be enough interest, it will also be combined with experimental research studies in the area. By joining the data resulting from this study to additional regional research studies, the formula will be able to increase its accuracy, statistical inference, and applicability, serving as a representation of the need for region-specific standards and a reminder that a universal time since death estimate is still not applicable in all areas.

Most importantly, the models derived in this area are directly applicable to the medico-legal community, offering an accurate method by which to estimate time since death in a variety of depositional contexts.

Summary of Discussion

Based on the multitude of qualitative and quantitative analyses conducted, a number of important points have been discussed, functioning to piece together the puzzle regarding decomposition. When these considerations are evaluated jointly in conjunction with the results derived from this study, they combine to form a rather substantial understanding of the processes involved in decay, resulting in the production of a time since death equation well-suited to assessing decomposition in the Delaware River Valley Region.

To begin, total body score has been identified as playing a fundamental role in decomposition models designed to quantitatively estimate time since death. Not only has it been demonstrated that a distinct progression to decomposition exists in the Delaware

River Valley Region, compared to total body score descriptions developed in other environments, but total body score has been identified as providing a statistically significant effect across decomposition models. In fact, given the linear dependence identified between the various factors analyzed in this study, it becomes readily apparent that a representative and accurate depiction of the decompositional patterns particular to an area, summarized in the total body score descriptions, is the most important component of an accurate time since death estimation equation.

Secondly, without a doubt, accumulated degree days explain more of the variation in decomposition compared to a simple measure of time, demonstrated in the form of post-mortem interval days. Across each and every model developed in this study, regardless of the stratification of depositional contexts or the inclusion of all cases into one general dataset, this find holds true. This particular discovery is crucial to forming the basis for the development of a time since death equation. What's more, by standardizing time and temperature in the form of accumulated degree days, region-specific standards can be developed across the United States and the World, utilizing the same general methodology employed in this study.

Next, the development of context specific time since death equations is certainly valid. However, given the low proportion of variation explained in models derived from aquatic environments, it is clear that as-yet-unknown variables exist which render the modeling of decomposition in water rather difficult. Given the inability to track such transient variables as tides, currents, variations in temperature, salinity level differences, adipocere development, and much more, it quickly becomes clear that in order to develop time since death equations specifically designed for aquatic cases, very specialized models, incorporating a number of factors not encountered on land or in indoor environments, are needed.

In regards to non-water outdoor and indoor cases, similarities are observed between decomposition in both contexts. Firstly, save for very few variables, cases exposed to either depositional environment tend to be subjected to similar factors. As a result, the pattern of decompositional changes and stages tend to overlap, justifying the use of total body score descriptions applicable to cases found in either context. Most importantly, when taken together, a model can be designed which explains a great deal of the variation in decomposition and produces accurate estimates of the time since death.

Furthermore, in terms of the identification of covariates which play statistically significant roles in the decomposition process, it once again becomes clear that total body score plays the most prominent role. Despite the potential relationships observed between both precipitation and insect activity on the log of ADD, no other variable comes to the forefront as demonstrating a statistically significant effect across models, with the effects of precipitation and insect activity requiring a larger sample size to be drawn out. This lack of consensus however, is not a sign of the inability to identify the important variables involved in decay. Instead, what this discovery indicates is that the roles played by each individual variable are so inextricably linked to each other, that they are unable to be parceled apart. Along the same vein, the consistent theme observed throughout the analysis is that their joint effects are represented in one critical variable, the total body score. Given the fact that each variable has the potential to speed up or slow down the rate of decay and contribute to the decompositional process, their effects are demonstrated jointly in the decomposition changes demonstrated in the total body score for each case.

Moreover, when the formulas derived for the various depositional contexts analyzed in this study were applied to range of total body scores possible, the resulting predicted ADD values demonstrated important insights regarding the rate of decay in each subset. Initially, the indoor cases demonstrated a more rapid progression to early decompositional changes, followed by outdoor cases. However, when applied to total body scores past the first half of the early decomposition stage, the rate changed, with outdoor cases demonstrating the fastest rate of decay. What's more, the outdoor and indoor model also proved to show rate of decay in between that of the outdoor and indoor rates previously described. In this way, it demonstrates the utility of the combined model to cases in both contexts.

Lastly, and most importantly, when compared to the Delaware River Valley model developed in this study, the decompositional model and time since death regression equation developed in the Megyesi et al. (2005) study explains a smaller proportion of the variation in decomposition when applied to data derived from the Delaware area. In fact, this particular discovery not only holds true in regards to the model incorporating all depositional contexts, but also in the model designed for non-water outdoor and indoor cases. Given the apparent need for a specific model developed solely for aquatic cases, this find takes on significant importance as the model derived from this study will likely be applied to non-water outdoor and indoor cases.

What's more, when both models were used to derive predicted accumulated degree days based on total body score assessments of non-water outdoor and indoor cases, as well as the entire dataset, the Delaware River Valley models more accurately approximated the actual observed ADD values each time, with a remarkable accuracy of only a two point differential between predicted and observed values when using the non-water outdoor and indoor Delaware River Valley model. Without a doubt, the Delaware River Valley model, especially the formula derived specifically for non-water outdoor and indoor cases, appears to be a more accurate, valid, and reliable means by which to estimate time since death in this area.

In total, the combination of results described above have not only led to the formulation of the very first decomposition models and time since death equations designed specifically for the Delaware River Valley Region, but they also serve to validate the development of region-specific standards.

Conclusion

In conclusion, this quantitative, retroactive study has served to address several critical needs in the criminal justice community while filling a significant gap in scientific knowledge regarding the process of decomposition as it applies to southeastern Pennsylvania, New Jersey, and Delaware. It has helped increase the accuracy, reliability, and validity of time since death estimates in decomposition cases and met the need for improved quantitative methods with statistically-backed error rates and confidence intervals. It has identified accumulated degree days and the total body score as playing key roles in the estimation of time since death and serving as central components in time since death estimation formulas. It has addressed the call for real-life, applied studies, under non-standard conditions, allowing for the application of the research directly to indoor, outdoor, and aquatic cases in the field. It has helped further the understanding of the environment's effects on decomposition in the United States and around the World. It has also provided law enforcement personnel with a quicker mechanism by which to track down leads, evaluate alibis and eyewitness accounts, identify matches to missing persons, and aid in the identification of unknown remains. Additionally, it has improved the practice of criminal justice by providing Medical Examiners, forensic experts, and criminal investigators with a foundation upon which they can lay claims regarding time since death estimations in a court of law and in criminal justice settings. Lastly, this study has not only validated the development of region-specific standards, but it has also created the first ever time since death estimation formula particular to the Delaware River Valley region.

Appendices

Appendix A: Tables

Early Approaches to Decompositional Stage Delineation

Table 1. Depiction of "Typical" Four Discrete Decompositional Stages: Fresh, Bloat, Decay, and Dry (Adapted from Rodriguez and Bass 1983)

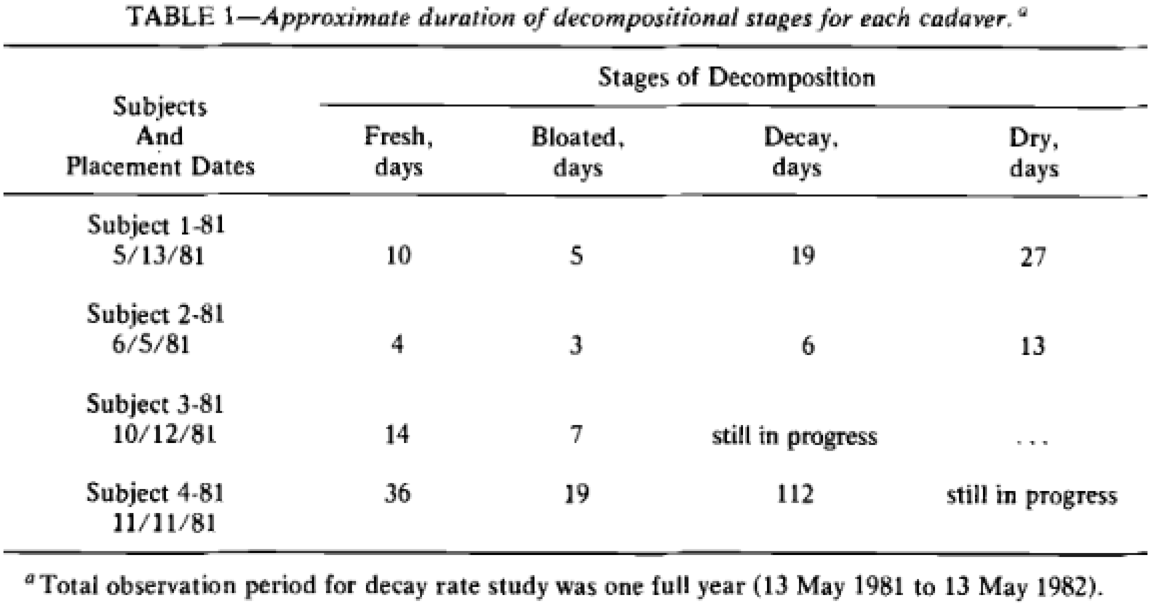


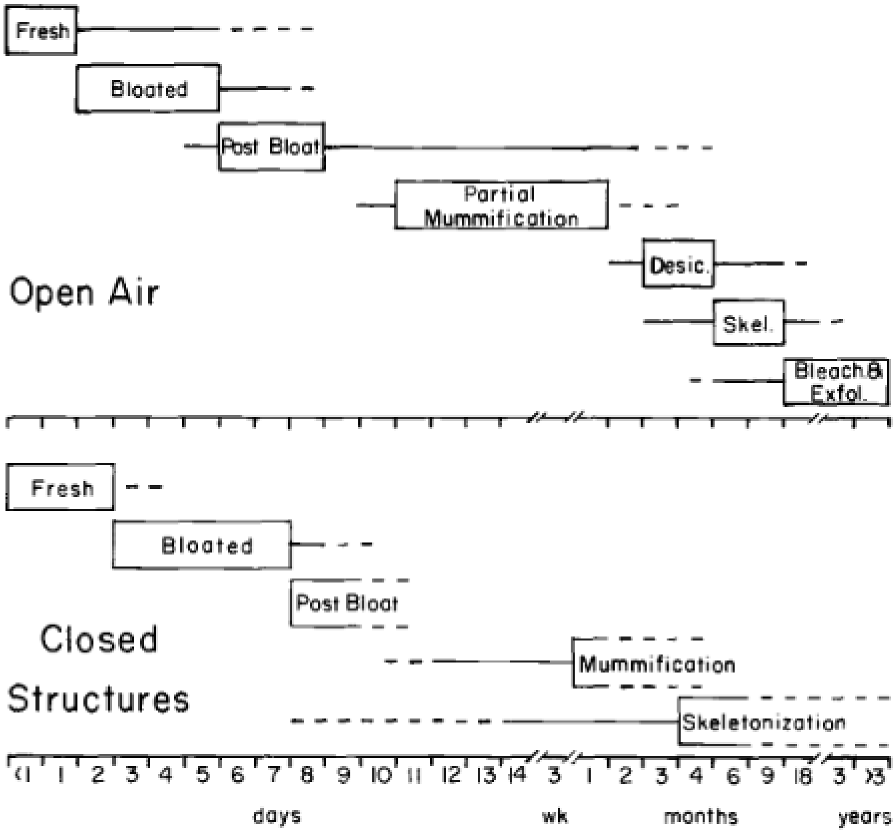
TABLE 1—*Approximate duration of decompositional stages for each cadaver.*[a]

Subjects And Placement Dates	Stages of Decomposition			
	Fresh, days	Bloated, days	Decay, days	Dry, days
Subject 1-81 5/13/81	10	5	19	27
Subject 2-81 6/5/81	4	3	6	13
Subject 3-81 10/12/81	14	7	still in progress	. . .
Subject 4-81 11/11/81	36	19	112	still in progress

[a] Total observation period for decay rate study was one full year (13 May 1981 to 13 May 1982).

Quantitative Descriptions of Decomposition "Correlated" with Time

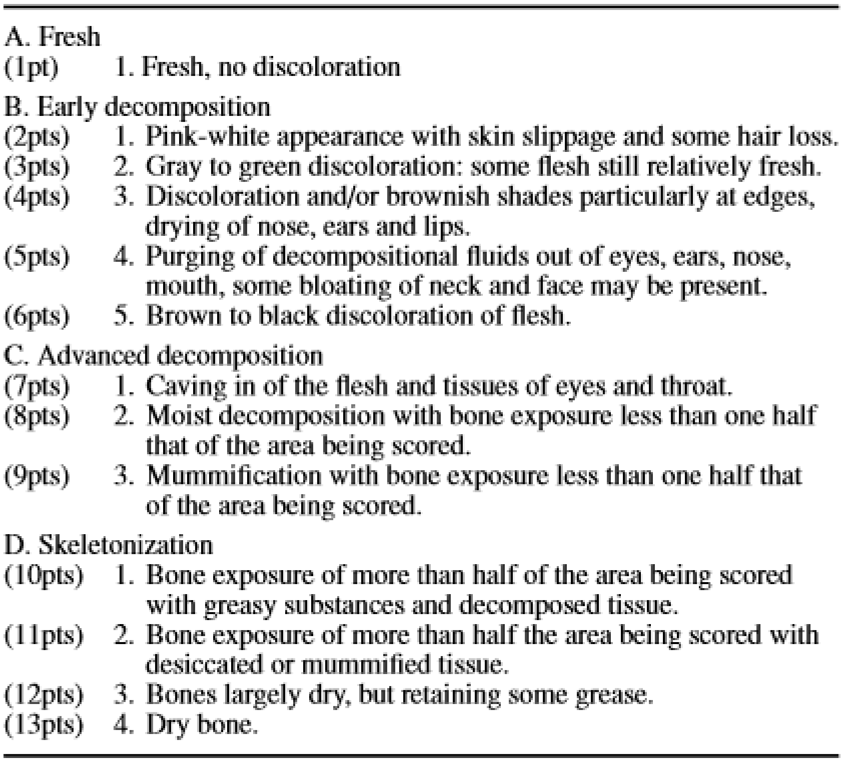
Table 2. Stages of Decomposition by Time in Open Air and Closed Structures (Adapted from Galloway et al. 1989)



Total Body Score System as per Megyesi et al. 2005

Head and Neck

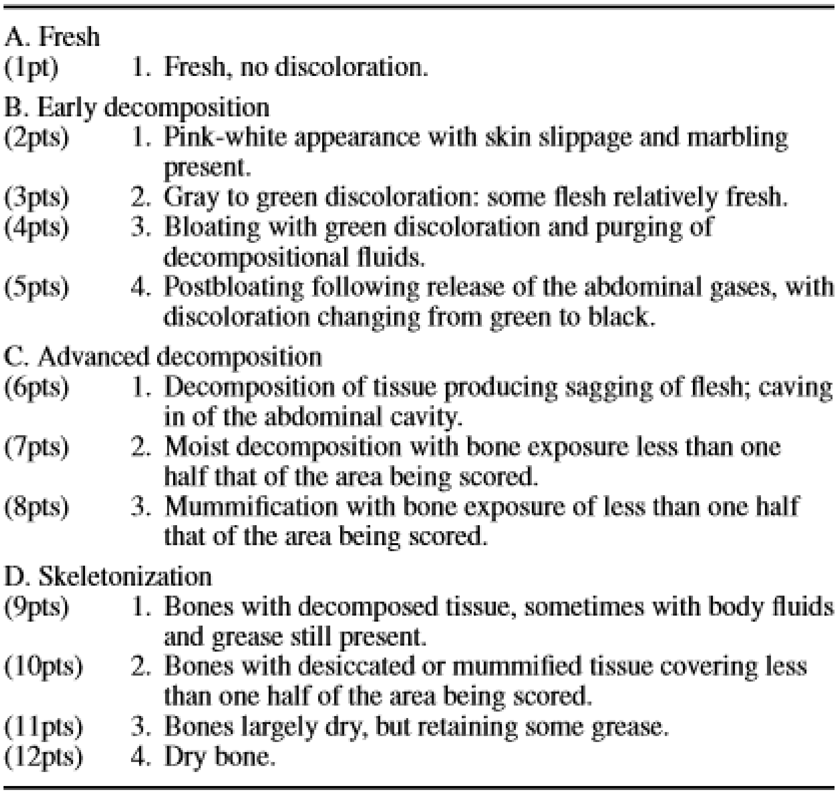
Table 3. Categories and Stages of Decomposition for the Head and Neck (Adapted from Megyesi et al. 2005)



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

Trunk

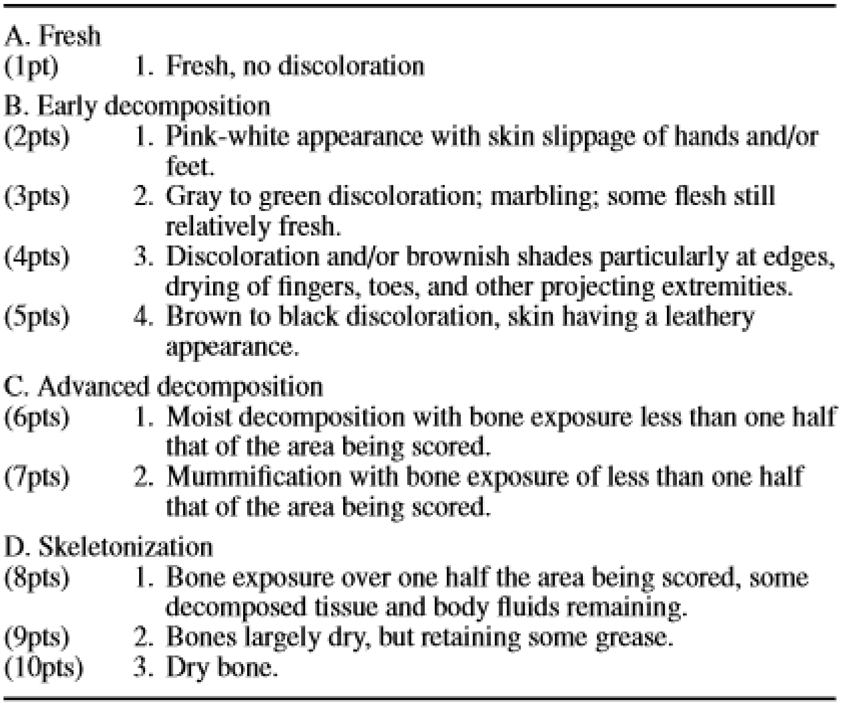
Table 4. Categories and Stages of Decomposition for the Trunk (Adapted from Megyesi et al. 2005)



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

Limbs

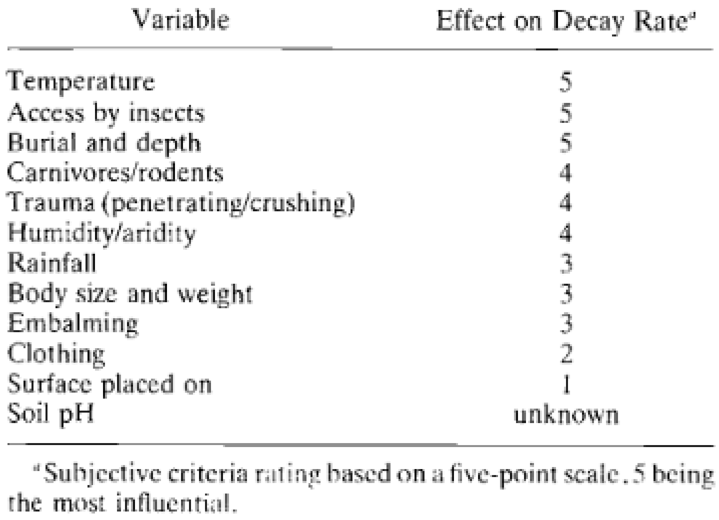
Table 5. Stages and Categories of Decomposition for the Limbs (Adapted from Megyesi et al. 2005)



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

Variables Affecting the Rate of Decay

Table 6. Variables Affecting Decay Rate of Human Body (Adapted from Mann et al. 1990)



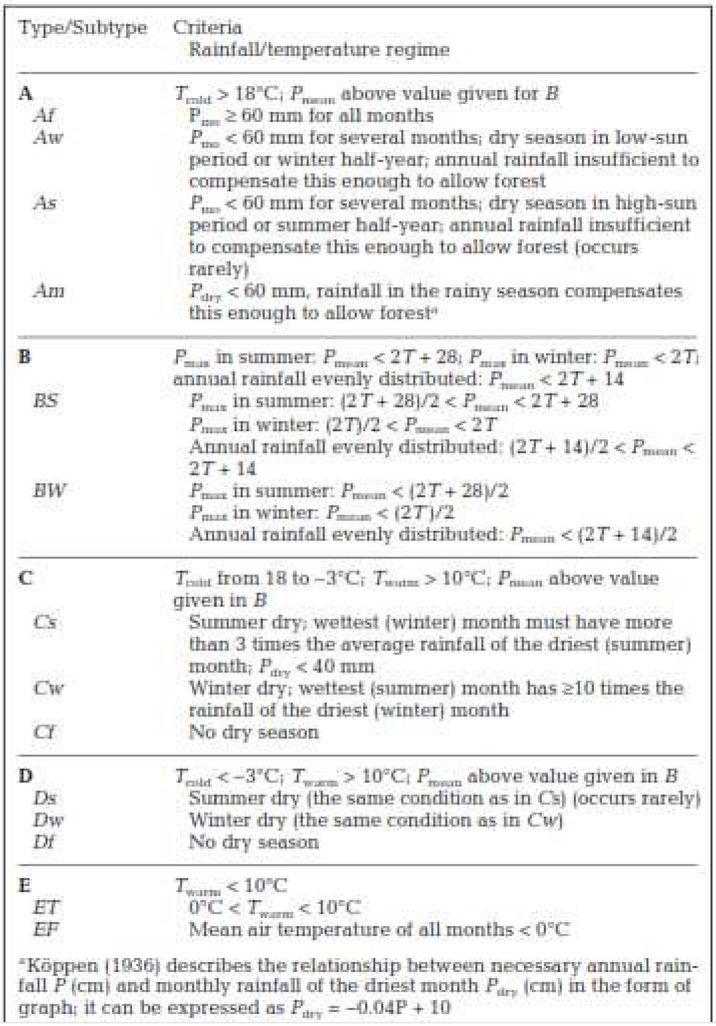
Variable	Effect on Decay Rate[a]
Temperature	5
Access by insects	5
Burial and depth	5
Carnivores/rodents	4
Trauma (penetrating/crushing)	4
Humidity/aridity	4
Rainfall	3
Body size and weight	3
Embalming	3
Clothing	2
Surface placed on	1
Soil pH	unknown

[a] Subjective criteria rating based on a five-point scale, 5 being the most influential.

Köppen-Geiger Definitions of Climate Types and Sub-Types

Table 7. Climate Types and Sub-Types Defined by Köppen-Geiger Classification System (Adapted from Belda et al. 2014)

T: mean annual temperature in Celsius; T_{mo}: mean montly temperature in Celsius; P_{mean}: mean annual rainfall in centimeters; P_{dry}: monthly rainfall of the driest summer month; P_{max}: maximum annual precipitation rainfall; P_{mo}: monthly precipitation; $T_{cold(warm)}$: monthly mean air temperature of the coldest (warmest) month

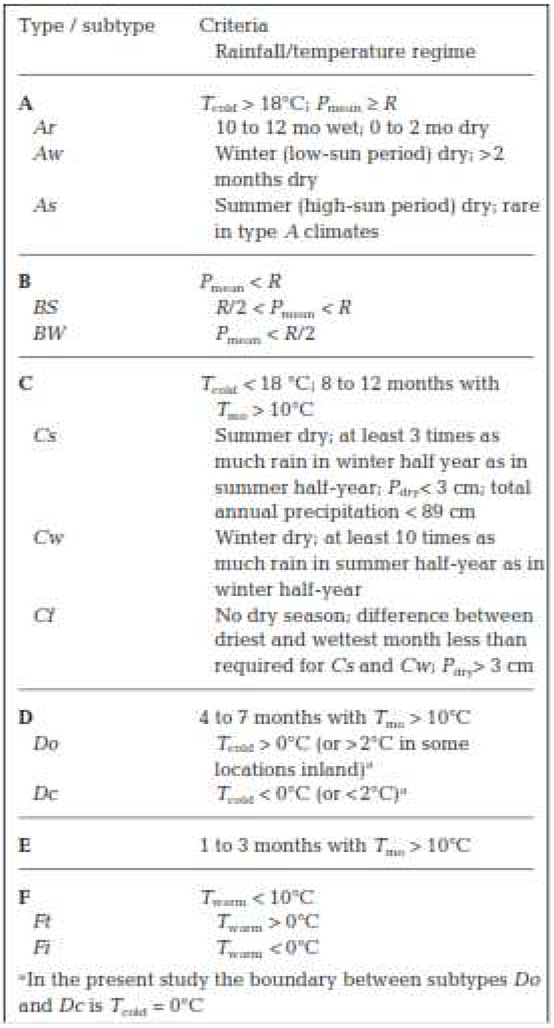


Type/Subtype	Criteria Rainfall/temperature regime
A	$T_{cold} > 18°C$; P_{mean} above value given for *B*
Af	$P_{mo} \geq 60$ mm for all months
Aw	$P_{mo} < 60$ mm for several months; dry season in low-sun period or winter half-year; annual rainfall insufficient to compensate this enough to allow forest
As	$P_{mo} < 60$ mm for several months; dry season in high-sun period or summer half-year; annual rainfall insufficient to compensate this enough to allow forest (occurs rarely)
Am	$P_{dry} < 60$ mm, rainfall in the rainy season compensates this enough to allow forest[a]
B	P_{max} in summer: $P_{mean} < 2T + 28$; P_{max} in winter: $P_{mean} < 2T$; annual rainfall evenly distributed: $P_{mean} < 2T + 14$
BS	P_{max} in summer: $(2T + 28)/2 < P_{mean} < 2T + 28$ P_{max} in winter: $(2T)/2 < P_{mean} < 2T$ Annual rainfall evenly distributed: $(2T + 14)/2 < P_{mean} < 2T + 14$
BW	P_{max} in summer: $P_{mean} < (2T + 28)/2$ P_{max} in winter: $P_{mean} < (2T)/2$ Annual rainfall evenly distributed: $P_{mean} < (2T + 14)/2$
C	T_{cold} from 18 to $-3°C$; $T_{warm} > 10°C$; P_{mean} above value given in *B*
Cs	Summer dry; wettest (winter) month must have more than 3 times the average rainfall of the driest (summer) month; $P_{dry} < 40$ mm
Cw	Winter dry; wettest (summer) month has ≥10 times the rainfall of the driest (winter) month
Cf	No dry season
D	$T_{cold} < -3°C$; $T_{warm} > 10°C$; P_{mean} above value given in *B*
Ds	Summer dry (the same condition as in *Cs*) (occurs rarely)
Dw	Winter dry (the same condition as in *Cw*)
Df	No dry season
E	$T_{warm} < 10°C$
ET	$0°C < T_{warm} < 10°C$
EF	Mean air temperature of all months $< 0°C$

[a] Köppen (1936) describes the relationship between necessary annual rainfall *P* (cm) and monthly rainfall of the driest month P_{dry} (cm) in the form of graph; it can be expressed as $P_{dry} = -0.04P + 10$

Table 8. Climate Types and Sub-Types Defined by Köppen-Trewartha Classification System (Adapted from Belda et al. 2014)

T: mean annual temperature in Celsius; T_{mo}: mean montly temperature in Celsius; P_{mean}: mean annual rainfall in centimeters; P_{dry}: monthly rainfall of the driest summer month; R: Patton's precipitation threshold; $T_{cold(warm)}$: monthly mean air temperature of the coldest (warmest) month



Type / subtype	Criteria Rainfall/temperature regime
A	$T_{cold} > 18°C$; $P_{mean} \geq R$
Ar	10 to 12 mo wet; 0 to 2 mo dry
Aw	Winter (low-sun period) dry; >2 months dry
As	Summer (high-sun period) dry; rare in type *A* climates
B	$P_{mean} < R$
BS	$R/2 < P_{mean} < R$
BW	$P_{mean} < R/2$
C	$T_{cold} < 18$ °C; 8 to 12 months with $T_{mo} > 10°C$
Cs	Summer dry; at least 3 times as much rain in winter half year as in summer half-year; $P_{dry} < 3$ cm; total annual precipitation < 89 cm
Cw	Winter dry; at least 10 times as much rain in summer half-year as in winter half-year
Cf	No dry season; difference between driest and wettest month less than required for *Cs* and *Cw*; $P_{dry} > 3$ cm
D	4 to 7 months with $T_{mo} > 10°C$
Do	$T_{cold} > 0°C$ (or >2°C in some locations inland)[a]
Dc	$T_{cold} < 0°C$ (or <2°C)[a]
E	1 to 3 months with $T_{mo} > 10°C$
F	$T_{warm} < 10°C$
Ft	$T_{warm} > 0°C$
Fi	$T_{warm} < 0°C$

[a] In the present study the boundary between subtypes *Do* and *Dc* is $T_{cold} = 0°C$

Accumulated Degree Day Group Dataset

Non-Water Outdoor Surface

Table 9. Non-Water, Outdoor, Surface Layer Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Soil Type/p.H.	Sun/Shade	Body Position	Insect Score	Penetrating Trauma	Scavenging Activity	Clothing Score
	Sex	Age	Ancestry	Height	Weight											
New Castle																
1	**M**	**47**	**White**	**N/A**	**N/A**	**62**	**650.277778**	**21**	**2.71 in**	**Unavailable/ Unavailable**	**Sun**	**Supine**	**4**	**No**	**No**	**9**
4	**M**	**72**	**White**	**N/A**	**N/A**	**277**	**3546.66667**	**36**	**35.2 in**	**Unavailable/ Unavailable**	**Sun**	**Unknown**	**0**	**Unknown**	**Yes**	**4**
5	**M**	**27**	**White**	**N/A**	**N/A**	**107**	**2333.05556**	**34**	**12.61 in**	**Silt Loam/6**	**Shade**	**Unknown**	**3**	**Yes**	**No**	**6**
6	**F**	**66**	**White**	**61 in.**	**N/A**	**142**	**2555**	**35**	**22.09 in**	**Unavailable/ Unavailable**	**Sun**	**Unknown**	**3**	**Unknown**	**Yes**	**4.25**
9	**M**	**43**	**White**	**N/A**	**106 lbs.**	**49**	**1245.83333**	**28**	**13.03 in**	**Sandy Loam/5.6**	**Shade**	**Supine**	**3**	**No**	**Yes**	**4**
10	**M**	**62**	**White**	**74 in.**	**145 lbs.**	**7**	**120**	**10**	**0.06 in**	**Unavailable/ Unavailable**	**Sun**	**Supine**	**5**	**No**	**No**	**2**
11	**M**	**25**	**White**	**69 in.**	**170 lbs.**	**10**	**174.722222**	**13**	**6.1 in**	**Silt Loam/6**	**Shade**	**Prone**	**4**	**No**	**No**	**7**
12	**F**	**37**	**Black**	**65 in.**	**137 lbs.**	**24**	**848.888889**	**17**	**5.52 in**	**Unavailable/ Unavailable**	**Shade**	**Supine**	**5**	**Yes**	**No**	**1**
13	**M**	**44**	**White**	**N/A**	**N/A**	**72**	**1079.44444**	**24**	**11.97 in**	**Loam/6**	**Shade**	**Prone**	**4**	**No**	**No**	**4**
14	**F**	**19**	**Black**	**N/A**	**N/A**	**120**	**2838.88889**	**39**	**10.79 in**	**Silt Loam/5.9**	**Shade**	**Unknown**	**0**	**Unknown**	**Yes**	**0**
15	**F**	**46**	**White**	**68 in.**	**165 lbs.**	**4**	**116.111111**	**13**	**0 in**	**Sandy Loam/5.5**	**Shade**	**Supine**	**2**	**No**	**Unknown**	**6**
Kent																
17	**M**	**37**	**White**	**N/A**	**N/A**	**169**	**3532.77778**	**34**	**22.66 in**	**Sandy Loam/6.2**	**Shade**	**Unknown**	**9**	**Yes**	**Yes**	**3**
18	**M**	**34**	**White**	**N/A**	**N/A**	**88**	**2215.55556**	**33**	**14.01 in**	**Unavailable/ Unavailable**	**Shade**	**Supine**	**3**	**Unknown**	**Yes**	**4**
Sussex																
20	**M**	**21**	**White**	**72 in.**	**252 lbs.**	**3**	**76.9444444**	**13**	**0.00 in**	**Moderately decomposed plant material/5.5**	**Shade**	**Supine**	**5**	**Yes**	**No**	**7**
21	**M**	**61**	**White**	**71 in.**	**164 lbs.**	**4**	**103.333333**	**10**	**0.07 in**	**Sandy Loam/6**	**Shade**	**Prone**	**6**	**Yes**	**No**	**3**
22	**M**	**49**	**White**	**N/A**	**280 lbs.**	**53**	**965.833333**	**31**	**5.72 in**	**Unavailable/ Unavailable**	**Shade**	**Prone**	**3**	**Unknown**	**No**	**8**

Non-Water Non-Surface Outdoor

Table 10. Non-Water, Non-Surface, Outdoor Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Sun/Shade	Body Position	Insect Score	Penetrating Trauma	Scavenging Activity	Clothing Score
	Sex	Age	Ancestry	Height	Weight										
New Castle															
23	M	27	Asian	63 in.	80 lbs.	72	1690.83333	24	7.72 in	Shade	Hanging	0	No	No	3.5
Sussex															
26	M	21	Hispanic	69 in.	134 lbs.	9	223.333333	13	0.03 in	Shade	Supine	3	No	No	4
27	M	52	White	67 in.	165 lbs.	9	223.333333	14	3.26 in	Shade	Seated	6	No	No	7
28	M	40	White	73 in.	175 lbs.	59	941.666667	24	8.5 in	Shade	Hanging	8	No	No	0

Indoor

Table 11. Indoor Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Body Position	Dirty	Insect Score	Penetrating Trauma	Scavenging Activity	Clothing Score
	Sex	Age	Ancestry	Height	Weight										
New Castle															
29	M	82	White	69.5 in.	155 lbs.	5	96.3888889	13	0.0 in	Supine	Yes	4	No	No	11
34	F	48	Black	68.5 in.	195 lbs.	19	347.5	17	2.87 in	Prone	No	2	No	No	0.5
35	M	62	White	72 in.	250 lbs.	14	276.111111	14	1.86 in	Right side	Yes	4	No	No	0
36	F	59	Black	66 in.	95 lbs.	15	285	11	3.99 in	Supine	No	5	No	No	4
37	M	43	Black	70 in.	101 lbs.	7	152.5	9	5.5 in	Prone	No	6	No	No	1
42	F	81	White	65 in.	143 lbs.	6	146.111111	9	1.03 in	Seated	No	4	No	No	7
44	M	71	Black	71 in.	105 lbs.	4	97.7777778	8	0.44 in	Supine	No	0	No	No	10
45	M	53	Black	64 in.	130 lbs.	15	175	14	2.1 in	Prone	No	3	No	No	1
47	M	85	White	67 in.	108 lbs.	8	138.333333	14	0.10 in	Supine	No	6	No	No	3
48	M	59	White	69 in.	205 lbs.	16	224.722222	11	4.51 in	Prone	No	0	No	No	0
49	M	49	White	67.5 in.	118 lbs.	15	77.2222222	9	3.39 in	Supine	Yes	0	No	No	7
50	M	63	White	70.5 in.	180 lbs.	16	405.833333	13	2.4 in	Supine	No	3	No	No	2
51	M	58	White	67.5 in.	155 lbs.	9	217.222222	14	0.84 in	Supine	No	3	No	No	0
52	F	77	White	65.5 in.	150 lbs.	12	271.388889	14	0.35 in	Supine	No	2	No	No	6.5
53	M	50	White	70 in.	184 lbs.	17	110.277778	13	7.42 in	Supine	No	0	No	No	2
55	F	63	White	66 in.	175 lbs.	32	683.611111	19	9.19 in	Prone	Yes	4	No	Yes	1.75
56	F	73	White	64 in.	91 lbs.	12	292.777778	12	3.87 in	Unknown	Yes	0	No	No	3.25
57	F	88	White	64.5 in.	142 lbs.	19	107.222222	13	2.15 in	Unknown	No	0	No	No	4
58	M	53	Black	67.5 in.	180 lbs.	9	198.055556	13	0.17 in	Supine	No	0	Yes	No	7
60	M	56	White	72.5 in.	153 lbs.	21	464.722222	16	3.52 in	Prone	No	4	No	No	3
61	M	71	White	65 in.	93 lbs.	11	92.2222222	11	0.55 in	Supine	No	0	No	No	2
62	M	77	White	65.5 in.	162 lbs.	90	278.888889	20	9.45 in	Prone	No	9	No	No	0
63	M	41	Black	72 in.	190 lbs.	12	271.666667	12	1.9 in	Supine	No	4	No	No	5
64	F	54	White	58 in.	100 lbs.	53	427.777778	18	7.23 in	Prone	No	3	No	No	0
65	F	32	White	67 in.	115 lbs.	8	176.388889	13	0.93 in	Prone	No	2	No	No	3.5
66	F	87	White	62 in.	94 lbs.	15	226.944444	14	1.02 in	Supine	No	6	No	No	1.75
68	F	77	White	62 in.	125 lbs.	21	282.5	14	0.49 in	Supine	No	4	No	No	4.75
Kent															
69	M	74	White	70 in.	120 lbs.	16	391.666667	15	1.77 in	Supine	No	3	No	No	0
71	M	56	Black	70 in.	110 lbs.	4	103.611111	13	0.4 in	Prone	No	4	No	No	3
72	F	62	White	63 in.	125 lbs.	5	116.111111	10	0.01 in	Right side	No	4	No	No	4
73	M	70	White	73 in.	312 lbs.	5	57.2222222	11	0.00 in	Left side	Yes	0	No	No	0
74	M	78	White	69 in.	101 lbs.	32	250	16	3.06 in	Supine	No	0	No	No	6
76	F	61	White	N/A	125 lbs.	50	1327.77778	22	4.36 in	Supine	Yes	0	No	No	0
77	F	62	White	65 in.	125 lbs.	9	222.5	16	0.17 in	Supine	No	4	No	No	1.25
78	F	45	White	68 in.	105 lbs.	17	45.2777778	12	1.37 in	Right side	No	0	No	No	3
Sussex															
79	M	35	Black	70 in.	31 lbs.	24	578.611111	22	4.72 in	Left side	Yes	5	Yes	No	3
80	M	93	White	66 in.	55 lbs.	22	541.388889	20	5.08 in	Prone	No	3	No	No	3.75

Aquatic

Table 12. Aquatic Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Body Position	Water Salinity	Insect Score	Penetrating Trauma	Scavenging	Clothing Score
	Sex	Age	Ancestry	Height	Weight										
New Castle															
81	M	21	Black	Unknown	Unknown	9	239.05	15	2.45 in.	Prone	Fresh-water	4	No	No	1
83	F	36	White	63.5 in.	130 lbs.	8	191.805556	12	0.64 in	Supine	Low	0	No	No	5
84	M	42	White	70 in.	200 lbs.	8	191.805556	12	0.64 in	Seated	Low	0	No	No	3
86	M	66	White	72 in.	310 lbs.	14	162.2	8	2.49 in	Unknown	Medium	0	Yes	No	4
88	M	49	Black	69 in.	265 lbs.	127	462.5	13	9.9 in	Unknown	Low	0	No	Yes	9
89	M	75	Black	66.5 in.	105 lbs.	28	789.5	18	4.97 in	Unknown	Medium	3	No	Yes	2
90	M	34	White	71 in.	200 lbs.	7	120.9	11	0.96 in	Unknown	Medium	0	No	Yes	6.75
91	M	39	Black	67 in.	200 lbs.	30	251.6	12	2.19 in	Unknown	Low	0	No	No	9.5
92	M	57	Black	66 in.	265 lbs.	3	78.2129444	12	0.00 in	Prone	Low-Medium	0	No	No	6
93	M	49	Black	68 in.	220 lbs.	3	82.57	9	0.24 in	Unknown	Low	0	No	Yes	6
94	M	30	White	73 in.	282 lbs.	2	47.9022222	11	0.07 in	Prone	Medium	0	No	No	7
96	M	48	White	70.5 in.	275 lbs.	14	146.041222	9	1.66 in	Prone	Low-Medium	0	No	Yes	5
97	M	50	Black	70 in.	245 lbs.	18	173.310167	12	1.66 in	Unknown	Low	0	No	Yes	8
98	M	42	White	70 in.	150 lbs.	4	109.884889	11	0.00 in	Unknown	Low-Medium	0	No	No	0
99	M	54	Black	67.5 in.	168 lbs.	3	84.1021667	11	0.98 in	Unknown	Medium	0	No	No	7
101	M	40	White	69 in.	143 lbs.	174	1138.85	20	20.53 in	Unknown	Medium	0	No	Yes	3
104	M	33	White	68 in.	215 lbs.	6	108.402667	10	0.02 in	Unknown	Medium	0	No	No	3
105	F	46	White	64.5 in.	160 lbs.	20	208.9	11	2.22 in	Unknown	Low-Medium	0	No	No	9
110	M	16	White	69 in.	153 lbs.	6	122.728889	10	2.86 in	Unknown	Medium	0	No	Yes	6
Kent															
114	M	19	White	71 in.	173 lbs.	17	189.8	9	2.11 in	Unknown	Low	0	No	Yes	10.25
115	M	40	White	69 in.	190 lbs.	9	112.5	11	1.34 in	Unknown	High	0	No	No	8
117	M	26	White	70 in.	197 lbs.	2	54.5332778	11	0.43 in	Unknown	High Medium	0	No	No	6
Sussex															
124	M	35	Asian	67 in.	150 lbs.	8	99	13	2.86 in	Supine	Open Water	0	Yes	Yes	0

Post-Mortem Interval Group Dataset

<u>Non-Water Outdoor Surface</u>

Table 13. Non-Water, Outdoor, Surface Layer Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Soil Type/p.H.	Sun/Shade	Body Position	Insect Score	Penetrating Trauma	Scavenging Activity	Clothing Score
	Sex	Age	Ancestry	Height	Weight											
<u>New Castle</u>																
1	M	47	White	N/A	N/A	62	650.277778	21	2.71 in	Unavailable/ Unavailable	Sun	Supine	4	No	No	9
5	M	27	White	N/A	N/A	107	2333.05556	34	12.61 in	Silt Loam/6	Shade	Unknown	3	Yes	No	6
6	F	66	White	61 in.	N/A	142	2555	35	22.09 in	Unavailable/ Unavailable	Sun	Unknown	3	Unknown	Yes	4.25
9	M	43	White	N/A	106 lbs.	49	1245.83333	28	13.03 in	Sandy Loam/5.6	Shade	Supine	3	No	Yes	4
10	M	62	White	74 in.	145 lbs.	7	120	10	0.06 in	Unavailable/ Unavailable	Sun	Supine	5	No	No	2
11	M	25	White	69 in.	170 lbs.	10	174.722222	13	6.1 in	Silt Loam/6	Shade	Prone	4	No	No	7
12	F	37	Black	65 in.	137 lbs.	24	848.888889	17	5.52 in	Unavailable/ Unavailable	Shade	Supine	5	Yes	No	1
13	M	44	White	N/A	N/A	72	1079.44444	24	11.97 in	Loam/6	Shade	Prone	4	No	No	4
14	F	19	Black	N/A	N/A	120	2838.88889	39	10.79 in	Silt Loam/5.9	Shade	Unknown	0	Unknown	Yes	0
15	F	46	White	68 in.	165 lbs.	4	116.111111	13	0 in	Sandy Loam/5.5	Shade	Supine	2	No	Unknown	6
<u>Kent</u>																
17	M	37	White	N/A	N/A	169	3532.77778	34	22.66 in	Sandy Loam/6.2	Shade	Unknown	9	Yes	Yes	3
18	M	34	White	N/A	N/A	88	2215.55556	33	14.01 in	Unavailable/ Unavailable	Shade	Supine	3	Unknown	Yes	4
<u>Sussex</u>																
21	M	61	White	71 in.	164 lbs.	4	103.333333	10	0.07 in	Sandy Loam/6	Shade	Prone	6	Yes	No	3
22	M	49	White	N/A	280 lbs.	53	965.833333	31	5.72 in	Unavailable/ Unavailable	Shade	Prone	3	Unknown	No	8

Non-Water Non-Surface Outdoor

Table 14. Non-Water, Non-Surface, Outdoor Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Sun/Shade	Body Position	Insect Score	Penetrating Trauma	Scavenging Activity	Clothing Score
	Sex	Age	Ancestry	Height	Weight										
New Castle															
23	M	27	Asian	63 in.	80 lbs.	72	1690.83333	24	7.72 in	Shade	Hanging	0	No	No	3.5
Sussex															
26	M	21	Hispanic	69 in.	134 lbs.	9	223.333333	13	0.03 in	Shade	Supine	3	No	No	4
27	M	52	White	67 in.	165 lbs.	9	223.333333	14	3.26 in	Shade	Seated	6	No	No	7
28	M	40	White	73 in.	175 lbs.	59	941.666667	24	8.5 in	Shade	Hanging	8	No	No	0

Indoor

Table 15. Indoor Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Body Position	Dirty	Insect Score	Penetrating Trauma	Scavenging Activity	Clothing Score
	Sex	Age	Ancestry	Height	Weight										
New Castle															
29	M	82	White	69.5 in.	155 lbs.	5	96.3888889	13	0.0 in	Supine	Yes	4	No	No	11
34	F	48	Black	68.5 in.	195 lbs.	19	347.5	17	2.87 in	Prone	No	2	No	No	0.5
35	M	62	White	72 in.	250 lbs.	14	276.111111	14	1.86 in	Right side	Yes	4	No	No	0
36	F	59	Black	66 in.	95 lbs.	15	285	11	3.99 in	Supine	No	5	No	No	4
37	M	43	Black	70 in.	101 lbs.	7	152.5	9	5.5 in	Prone	No	6	No	No	1
42	F	81	White	65 in.	143 lbs.	6	146.111111	9	1.03 in	Seated	No	4	No	No	7
43	M	73	Black	65 in.	220 lbs.	14	19.7222222	13	1.35 in	Supine	No	0	Yes	No	13.5
44	M	71	Black	71 in.	105 lbs.	4	97.7777778	8	0.44 in	Supine	No	0	No	No	10
45	M	53	Black	64 in.	130 lbs.	15	175	14	2.1 in	Prone	No	3	No	No	1
46	F	70	White	67 in.	155 lbs.	8	14.4444444	13	0.52 in	Supine	No	0	No	No	3.75
47	M	85	White	67 in.	108 lbs.	8	138.333333	14	0.10 in	Supine	No	6	No	No	3
48	M	59	White	69 in.	205 lbs.	16	224.722222	11	4.51 in	Prone	No	0	No	No	0
49	M	49	White	67.5 in.	118 lbs.	15	77.2222222	9	3.39 in	Supine	Yes	0	No	No	7
50	M	63	White	70.5 in.	180 lbs.	16	405.833333	13	2.4 in	Supine	No	3	No	No	2
51	M	58	White	67.5 in.	155 lbs.	9	217.222222	14	0.84 in	Supine	No	3	No	No	0
52	F	77	White	65.5 in.	150 lbs.	12	271.388889	14	0.35 in	Supine	No	2	No	No	6.5
53	M	50	White	70 in.	184 lbs.	17	110.277778	13	7.42 in	Supine	No	0	No	No	2
55	F	63	White	66 in.	175 lbs.	32	683.611111	19	9.19 in	Prone	Yes	4	No	Yes	1.75
56	F	73	White	64 in.	91 lbs.	12	292.777778	12	3.87 in	Unknown	Yes	0	No	No	3.25
57	F	88	White	64.5 in.	142 lbs.	19	107.222222	13	2.15 in	Unknown	No	0	No	No	4
58	M	53	Black	67.5 in.	180 lbs.	9	198.055556	13	0.17 in	Supine	No	0	Yes	No	7
60	M	56	White	72.5 in.	153 lbs.	21	464.722222	16	3.52 in	Prone	No	4	No	No	3
61	M	71	White	65 in.	93 lbs.	11	92.2222222	11	0.55 in	Supine	No	0	No	No	2
62	M	77	White	65.5 in.	162 lbs.	90	278.888889	20	9.45 in	Prone	No	9	No	No	0
63	M	41	Black	72 in.	190 lbs.	12	271.666667	12	1.9 in	Supine	No	4	No	No	5
64	F	54	White	58 in.	100 lbs.	53	427.777778	18	7.23 in	Prone	No	3	No	No	0
65	F	32	White	67 in.	115 lbs.	8	176.388889	13	0.93 in	Prone	No	2	No	No	3.5
66	F	87	White	62 in.	94 lbs.	15	226.944444	14	1.02 in	Supine	No	6	No	No	1.75
68	F	77	White	62 in.	125 lbs.	21	282.5	14	0.49 in	Supine	No	4	No	No	4.75
Kent															
69	M	74	White	70 in.	120 lbs.	16	391.666667	15	1.77 in	Supine	No	3	No	No	0
71	M	56	Black	70 in.	110 lbs.	4	103.611111	13	0.4 in	Prone	No	4	No	No	3
72	F	62	White	63 in.	125 lbs.	5	116.111111	10	0.01 in	Right side	No	4	No	No	4
73	M	70	White	73 in.	312 lbs.	5	57.2222222	11	0.00 in	Left side	Yes	0	No	No	0
74	M	78	White	69 in.	101 lbs.	32	250	16	3.06 in	Supine	No	0	No	No	6
76	F	61	White	N/A	125 lbs.	50	1327.77778	22	4.36 in	Supine	Yes	0	No	No	0
77	F	62	White	65 in.	125 lbs.	9	222.5	16	0.17 in	Supine	No	4	No	No	1.25
78	F	45	White	68 in.	105 lbs.	17	45.2777778	12	1.37 in	Right side	No	0	No	No	3
Sussex															
79	M	35	Black	70 in.	31 lbs.	24	578.611111	22	4.72 in	Left side	Yes	5	Yes	No	3
80	M	93	White	66 in.	55 lbs.	22	541.388889	20	5.08 in	Prone	No	3	No	No	3.75

Aquatic

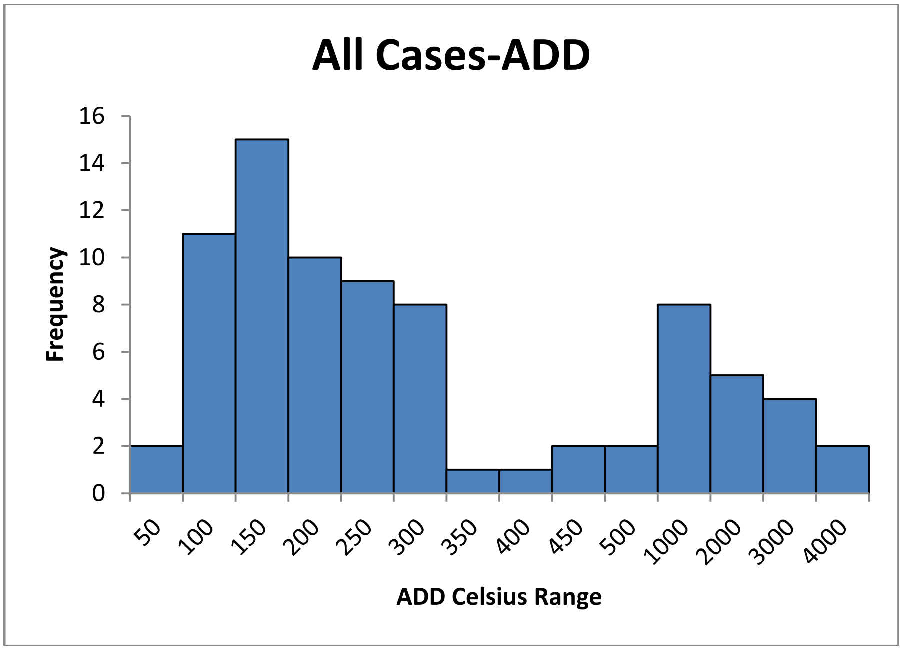
Table 16. Aquatic Case Information Summary Broken Up by County

Case #	Biological Profile					PMI	ADD Celsius	TBS	Precipitation	Body Position	Water Salinity	Insect Score	Penetrating Trauma	Scavenging	Clothing Score
	Sex	Age	Ancestry	Height	Weight										
New Castle															
81	M	21	Black	Unknown	Unknown	9	239.05	15	2.45 in.	Prone	Freshwater	4	No	No	1
83	F	36	White	63.5 in.	130 lbs.	8	191.805556	12	0.64 in	Supine	Low	0	No	No	5
84	M	42	White	70 in.	200 lbs.	8	191.805556	12	0.64 in	Seated	Low	0	No	No	3
86	M	66	White	72 in.	310 lbs.	14	162.2	8	2.49 in	Unknown	Medium	0	Yes	No	4
88	M	49	Black	69 in.	265 lbs.	127	462.5	13	9.9 in	Unknown	Low	0	No	Yes	9
89	M	75	Black	66.5 in.	105 lbs.	28	789.5	18	4.97 in	Unknown	Medium	3	No	Yes	2
90	M	34	White	71 in.	200 lbs.	7	120.9	11	0.96 in	Unknown	Medium	0	No	Yes	6.75
91	M	39	Black	67 in.	200 lbs.	30	251.6	12	2.19 in	Unknown	Low	0	No	No	9.5
96	M	48	White	70.5 in.	275 lbs.	14	146.041222	9	1.66 in	Prone	Low-Medium	0	No	Yes	5
97	M	50	Black	70 in.	245 lbs.	18	173.310167	12	1.66 in	Unknown	Low	0	No	Yes	8
98	M	42	White	70 in.	150 lbs.	4	109.884889	11	0.00 in	Unknown	Low-Medium	0	No	No	0
104	M	33	White	68 in.	215 lbs.	6	108.402667	10	0.02 in	Unknown	Medium	0	No	No	3
105	F	46	White	64.5 in.	160 lbs.	20	208.9	11	2.22 in	Unknown	Low-Medium	0	No	No	9
110	M	16	White	69 in.	153 lbs.	6	122.728889	10	2.86 in	Unknown	Medium	0	No	Yes	6
Kent															
114	M	19	White	71 in.	173 lbs.	17	189.8	9	2.11 in	Unknown	Low	0	No	Yes	10.25
115	M	40	White	69 in.	190 lbs.	9	112.5	11	1.34 in	Unknown	High	0	No	No	8
Sussex															
124	M	35	Asian	67 in.	150 lbs.	8	99	13	2.86 in	Supine	Open Water	0	Yes	Yes	0

Frequency and Range Histograms

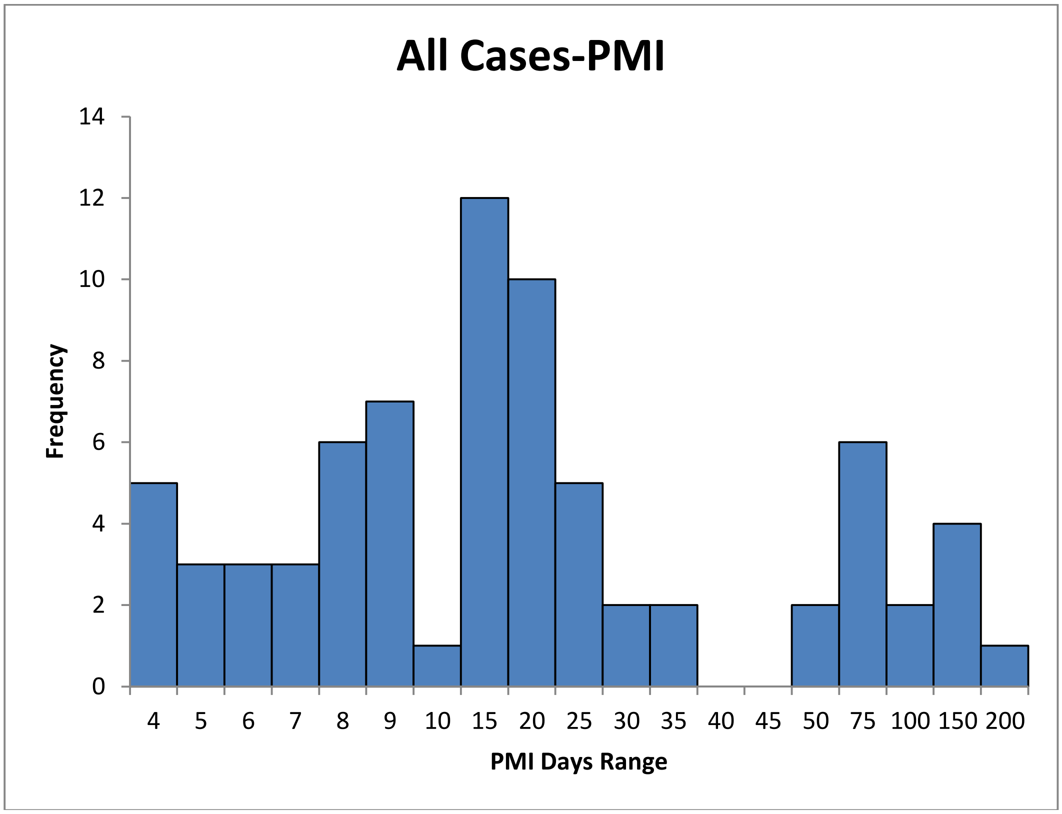
Accumulated Degree Day Frequency and Range

Table 17. Frequency and Range of Accumulated Degree Days (in degrees Celsius) included in the ADD dataset. Each bin includes the frequency of cases ranging from the start of the bin number down to the next lowest bin. The 50 ADD bin includes cases from 0-50 ADD.



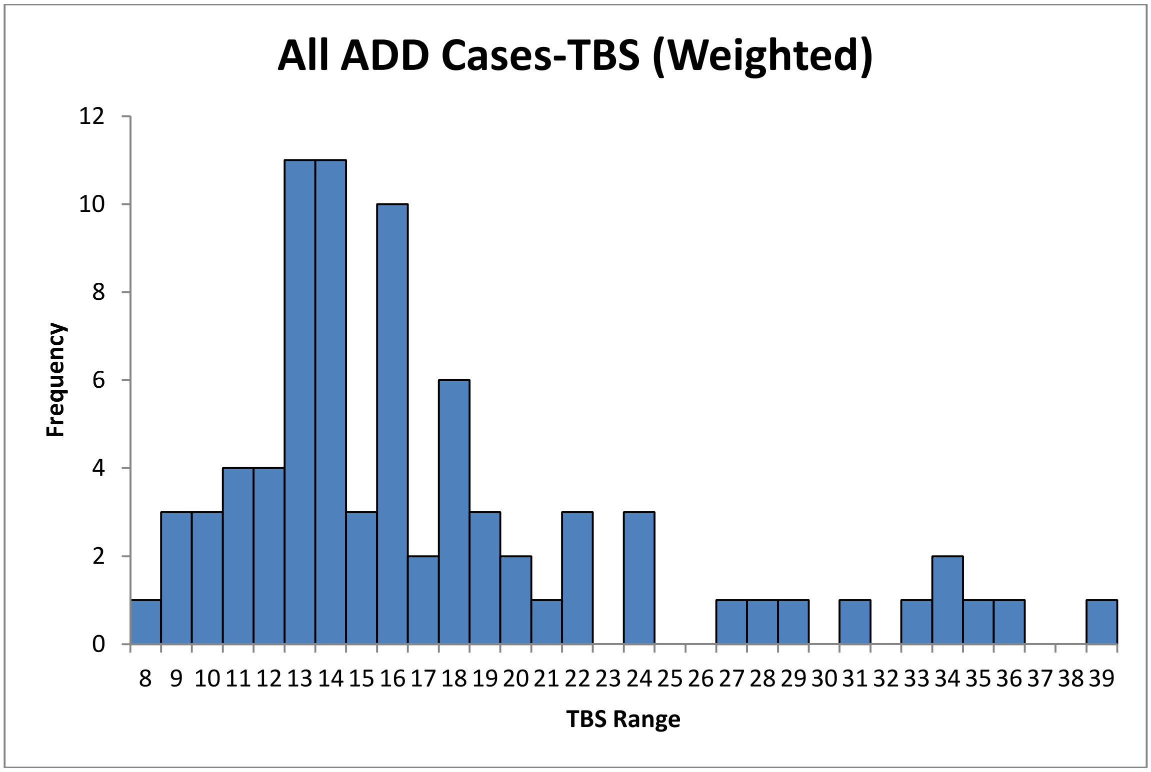
Post-Mortem Interval Days Frequency and Range

Table 18. Frequency and Range of Post-Mortem Interval Days included in the PMI dataset. Each bin includes the frequency of cases ranging from the start of the bin number down to the next lowest bin. The 4 PMI day bin includes cases from 0-4 PMI days.



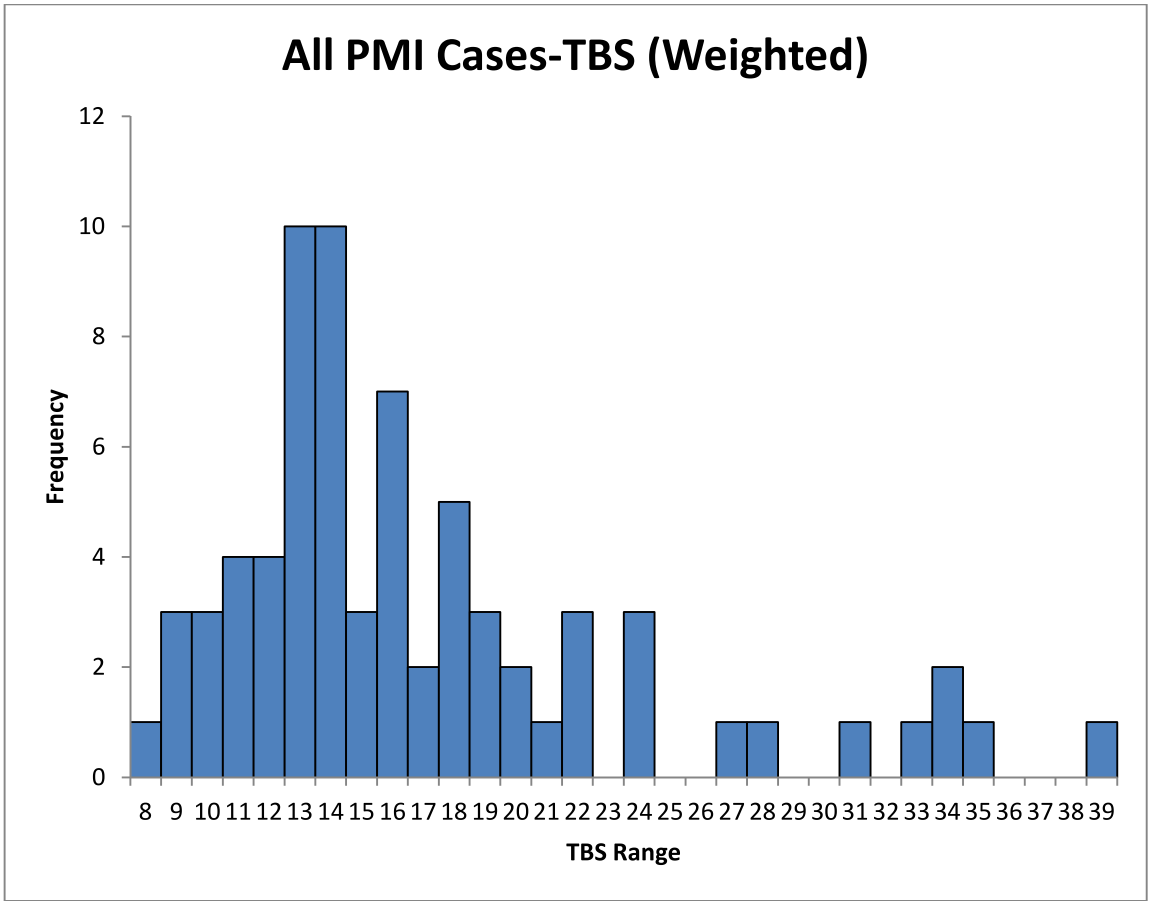
Total Body Score Frequency and Range: ADD

Table 19. Frequency and Range of Total Body Score included in the ADD dataset.



Total Body Score Frequency and Range: PMI

Table 20. Frequency and Range of Total Body Scores included in the PMI dataset.



Clothing Score System

Table 21. Scores Attributed to Clothing on the Head, Torso/Arms, Legs, and Feet

Area of the Body/Clothing Types	**Score**
Head	
a. Hat, Nightcap	1 point
Torso/Arms	
a. Bra	0.5 points
b. Tank Top, Nightgown	0.75 points
c. Blouse, T-Shirt, Shirt, Sheet	1 point
d. Robe, Long-Sleeve Shirt, Thermal Shirt, Sweater, Sweatshirt, Pajama Top, Blanket, Quilt	2 points
e. Jacket	3 points
Legs	
a. Underwear, Panties	0.5 points
b. Shorts, Boxershorts, Undershorts, Robe, Nightgown, Sheet	1 point
c. Pants, Jeans, Sweatpants, Pajama Bottoms, Thermals, Blanket, Quilt	2 points
Feet	
a. Sandals, One Sock	0.5 point
b. Two Socks, One Sneaker, Sheet	1 point
c. Two Sneakers, Two Boots, Two Shoes, Blanket	2 points

Water Salinity Score System

Table 22. Scores Attributed to Cases Based on Water Salinity Level

Water Salinity Level	Practical Salinity Units	Water Salinity Score
Freshwater	0	0
Low	0-5	1
Low-Medium	5-10	2
Medium	10-15	3
High-Medium	15-20	4
Low-High	20-25	5
High	25-30	6
Open Water	32 and Above	7

Non-Water Outdoor and Indoor Total Body Score System

Head and Neck

Table 23. Stages, Scores, and Descriptions of Decomposition for the Head and Neck

Stage/Score	**Description of Decompositional Changes**
A. Fresh	
1 point	Fresh, no discoloration
B. Early Decomposition	
2 points	Pink-white appearance with skin slippage and some hair loss.
3 points	Gray to green discoloration: some flesh still relatively fresh.
4 points	In addition to greenish and/or purplish discoloration, brownish shades particularly at edges, drying of nose, ears and lips.
5 points	Purging of decompositional fluids out of eyes, ears, nose, and mouth. Bloating of neck and face may be present with possible dark green/purple coloration. No exposure of bone. Not much more drying of tissues beyond the description provided in the previous stage.
6 points	Brown to black discoloration of flesh. Some slight (focal) exposure of bone possible. Possible drying over large areas or evidence of moist decay. Significant drying of skin not to be confused with leathery/mummified skin. Bloating may still be present or in process of waning.
C. Moderate Decomposition	
7 points	Brown leathery skin with no significant bone exposure (slight focal exposure possible) in area being scored. Mummification over large areas of the face may be present. Often accompanied by leathery skin in other areas of the body. No bloating usually present.
D. Advanced Decomposition	
8 points	Moist decomposition with bone exposure less than one half that of the area being scored (10-50%).
9 points	Mummification with bone exposure less than one half that of the area being scored (10-50%).
E. Skeletonization	
10 points	Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.
11 points	Bone exposure of more than half the area being scored with desiccated or mummified tissue. Hair may still be adherent to remaining tissue.
12 points	Bones completely devoid of soft tissue, or with slight adherences, with bone retaining grease.
13 points	Bones scattered away from main cluster of body due to animal activity.
14 points	Bones largely dry, but retaining some grease. No soft tissue adherences seen.
15 points	Dry bone.

Trunk

Table 24. Stages, Scores, and Descriptions of Decomposition for the Trunk

Stage/Score	**Description of Decompositional Changes**
A. Fresh	
1 point	Fresh, no discoloration
B. Early Decomposition	
2 points	Pink-white appearance with skin slippage and marbling present.
3 points	Gray to green discoloration, usually restricted to lower abdominal area: some flesh relatively fresh.
4 points	Bloating with green discoloration and purging of decompositional fluids. Body may also exhibit purple (may appear purple-red), black and/or sometimes brown discoloration and drying.
C. Moderate Decomposition	
5 points	Postbloating following release of the abdominal gases, with discoloration changing from green to black. In late stage, decomposition may produce sagging of tissue and caving in of the abdominal cavity.
6 points	Skin appears leathery/parchment-like, wrinkled, and deflated with very slight (focal) to no bone exposure in area being scored. Large areas of skin may be at point of mummification.
D. Advanced Decomposition	
7 points	Moist decomposition with bone exposure less than one half that of the area being scored (10-50%).
8 points	Mummification with bone exposure of less than one half that of the area being scored (10-50%).
E. Skeletonization	
9 points	Bones with decomposed tissue covering less than one half of the area being scored.
10 points	Bones with desiccated or mummified tissue covering less than one half of the area being scored.
11 points	Bones completely devoid of soft tissue, or with slight adherences as structure of soft tissue/muscles, etc. has collapsed (sometimes moist or desiccated sludge/putty/sticky tissue adherent to bone), with bone retaining grease.
12 points	Bones scattered away from main cluster of body due to animal activity.
13 points	Bones largely dry, but retaining some grease. No soft tissue adherences seen.
14 points	Dry bone.

Limbs

Table 25. Stages, Scores, and Descriptions of Decomposition for the Limbs

Stage/Score	**Description of Decompositional Changes**
A. Fresh	
1 point	Fresh, no discoloration
B. Early Decomposition	
2 points	Nearly completely fresh with pink-white appearance and skin slippage of hands and/or feet. Drying of tips of fingers/toes may be possible.
3 points	Gray to green discoloration; marbling; **some flesh still relatively fresh.** In indoor cases, fingers/fingertips and toes/toetips may be dried.
4 points	In addition to greenish and/or purplish and/or purple-red discoloration, dry brown shades predominantly at edges, drying of fingers/hands, toes/feet, heels and other projecting extremities, but can extend somewhat to larger areas. Gloving of skin of hands and feet possible.
C. Moderate Decomposition	
5 points	This stage reserved for brown/yellow-brown leathery/mummified skin showing little (focal) to no bone exposure. Brown to black discoloration, with skin typically having a leathery and sometimes dry wrinkled appearance. Hands and/or feet may be mummified and large areas of skin may be at point of mummification. It is distinguished from previous category by state of lower legs. If not mummified and exhibiting earlier stage traits, such as purplish, light brown, or greenish discoloration and skin slippage, then previous category should be used.
D. Advanced Decomposition	
6 points	Moist decomposition with bone exposure less than one half that of the area being scored (10-50%).
7 points	Mummification with bone exposure of less than one half that of the area being scored (10-50%).
E. Skeletonization	
8 points	Bones with decomposed tissue covering less than one half of the area being scored.
9 points	Bones with desiccated or mummified tissue covering less than one half of the area being scored.
10 points	Bones completely devoid of soft tissue, or with slight adherences only, with bone retaining grease.
11 points	Bones scattered away from main cluster of body due to animal activity.
12 points	Bones largely dry, but retaining some grease. No soft tissue adherences seen.
13 points	Dry bone.

Water Total Body Score System

Head and Neck

Table 26. Stages, Scores, and Descriptions of Decomposition for the Head and Neck

Stage/Score	**Description of Decompositional Changes**
A. Fresh	
1 point	No visible changes.
B. Early Decomposition	
2 points	Slight pink discoloration, darkened lips (blue), goose pimpling.
3 points	Reddening, sometimes dark, of face and neck with initial skin slippage. Marbling visible on face. Possible early signs of animal activity/predation—concentrated on the ears, nose, and lips. Early evidence of bloating, especially in the lips, may be seen. Brain softening and may be liquefied in small number of cases. Head hair beginning to slough off, mostly at front. Purge fluid may begin emanating.
4 points	Bloating of the entire face. Discoloration ranging from yellow/light brown to green with reddening remaining at times. Skin sloughing off. Head hair in process of sloughing off, or sometimes sloughed off. Brain is softened and nearing or at the point of liquefaction. Evidence of animal activity on ears, nose, and lips may remain or have become more prevalent exposing some underlying tissues in face, neck, and orbits. Purge fluid may be emanating or in process of waning.
C. Moderate Decomposition	
5 points	Face passed the point of bloating, taking on the look of more advanced decomposition of tissue. Anterior aspect of the face may have a slightly collapsed appearance, especially the nose. Head hair sloughed off. Brain liquefied. Tissue exposed on face and neck. Dark green/black discoloration.
D. Advanced Decomposition	
6 points	Less than half of bone exposed (10-50%)—concentrated over the orbital, frontal, and parietal regions. Some on the mandible and maxilla.
7 points	More extensive skeletonization on the cranium, with greater than half of bone exposed. Disarticulation of the mandible.
E. Skeletonization	
8 points	Complete disarticulation of the skull from torso. Some slight adherences of tissue remain. Bone retains off-white/light brown color.
9 points	Skull devoid of any soft tissue and bleached white in color, although some areas of light brown coloration or environmental staining may be evident. Evidence of erosion/weathering possible.

Trunk

Table 27. Stages, Scores, and Descriptions of Decomposition for the Trunk

Stage/Score	**Description of Decompositional Changes**
A. Fresh	
1 point	No visible changes.
B. Early Decomposition	
2 points	Slight pink discoloration, goose pimpling.
3 points	Yellow/light green discoloration of abdomen and reddening of upper chest (or occasionally a side). Marbling beginning. Internal organs beginning to soften. Slight scrotal bloating may be observed. Initial skin slippage. Possible early signs of predation. Some areas of skin may retain a relatively fresh appearance.
4 points	Light to dark green (sometimes blue) and yellow discoloration of abdomen, with possible reddening remaining. Stage defined by mild to full bloating of abdomen with mild to full bloating of scrotal sac in males. Marbling may still be present. Skin slippage. Organs show evidence of autolysis and marked softening.
C. Moderate Decomposition	
5 points	Dark green⁄purple discoloration, with no reddening or yellowing. Bloating remains. Side facing the sun may show brown dry/leathery skin.
D. Advanced Decomposition	
6 points	Black discoloration (may be white and black based on presence of adipocere), bloating becoming softer, initial exposure of internal organs with slight focal exposure of bones. Side facing the sun may show leathery/mummified skin.
7 points	Further loss of tissues and organs. Bone exposure is more extensive but less than half is exposed (10-50%).
E. Skeletonization	
8 points	Greater than half of bone is exposed. Soft tissue is still adherent and little to no organs remain.
9 points	Complete skeletonization and disarticulation with only slight soft tissue adherences remaining. Bone retains off-white/light brown color.
10 points	Bones nearly or completely bleached white and devoid of any soft tissue. Evidence of erosion possible.

Limbs

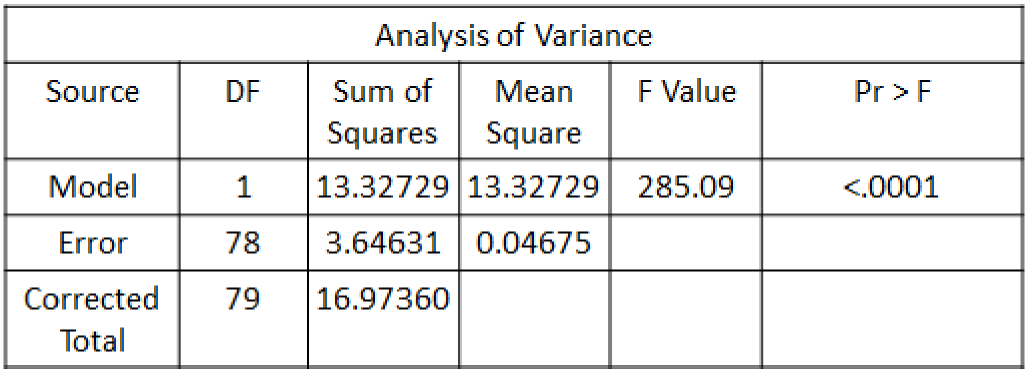
Table 28. Stages, Scores, and Descriptions of Decomposition for the Limbs

Stage/Score	**Description of Decompositional Changes**
A. Fresh	
1 point	No visible changes.
B. Early Decomposition	
2 points	Mild wrinkling of skin on hands and ⁄ or feet. Possible goose pimpling.
3 points	Skin on palms of hands and ⁄ or soles of feet becoming white, wrinkled, and thickened (washerwoman's hands/feet). Slight pink discoloration of arms and legs with possible early marbling. Slight focal skin slippage may be observed in select areas. Possible early signs of animal activity ⁄ predation. Some skin relatively fresh, especially in lower legs.
4 points	Skin on palms of hands and ⁄ or soles of feet becoming soggy and loose with some sloughing of hands. Stage defined by feet being in a less advanced stage of decomposition than the hands (but more advanced than previous stage). Initial skin slippage throughout limbs. Marbling or dark reddening (possibly purpling) of the limbs—predominantly on upper arms and possibly upper legs. Yellow-brown/light green (occasionally blue) discoloration of arms and/or legs. Signs of predation may be apparent.
C. Moderate Decomposition	
5 points	Skin on both the hands and feet sloughing off or completely degloved. Yellow-brown ⁄ green to green ⁄ purple/black discoloration on arms and legs. Skin slippage seen throughout arms and legs. Clear evidence of predation may be visible. Posterior aspects may show dry brown/leathery skin.
D. Advanced Decomposition	
6 points	Focal exposure of bones of hands and ⁄ or feet; a few bones of the hands/feet may be lost. Muscles, tendons, and small areas of bone exposed in lower arms and ⁄ or legs. Posterior aspects may show leathery/mummified skin.
7 points	Bones of hands and ⁄ or feet beginning to disarticulate with some soft tissue potentially adherent in some areas. Less than half of bones of upper arms and ⁄ or legs exposed (10-50%).
8 points	Bones of hands and ⁄ or feet beginning to disarticulate with some soft tissue potentially adherent in some areas. Greater than half of bones of upper arms and ⁄ or legs exposed.
E. Skeletonization	
9 points	Complete skeletonization and disarticulation of limbs with only slight soft tissue adherences remaining. Bone retains off-white/light brown color.
10 points	Bones nearly or completely bleached white and devoid of any soft tissue. Evidence of erosion possible.

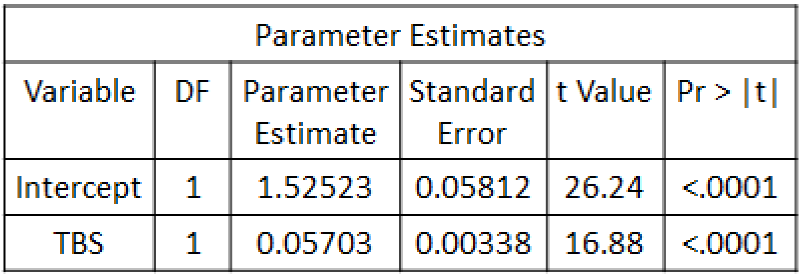
Overall Case Model

ADD Model: ANOVA and Parameter Estimates

Table 29. Analysis of Variance and Parameter Estimates for the Accumulated Degree Day Model. The *p*-values for statistical significance are displayed.



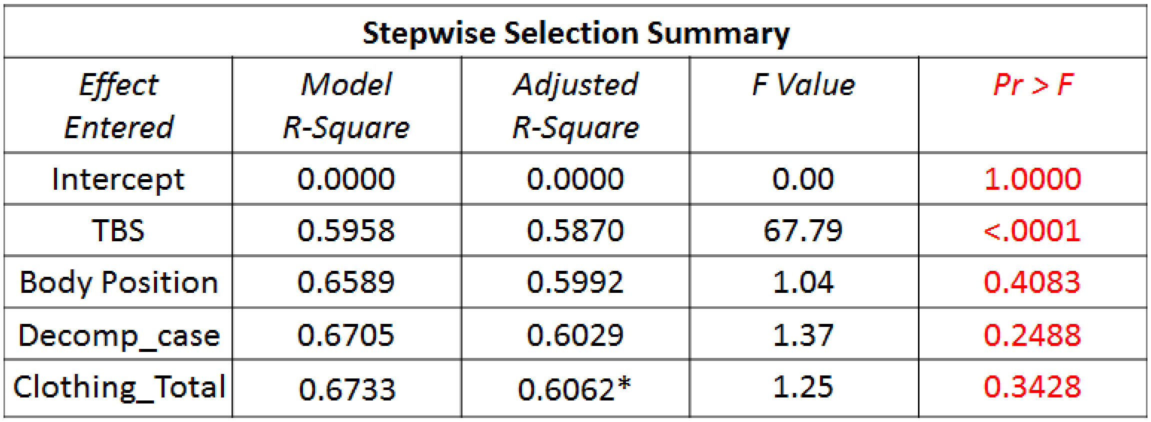
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	13.32729	13.32729	285.09	<.0001
Error	78	3.64631	0.04675		
Corrected Total	79	16.97360			



Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.52523	0.05812	26.24	<.0001
TBS	1	0.05703	0.00338	16.88	<.0001

ADD Model: Covariate Selection

Table 30. Stepwise Selection Summary of Covariates with the Highest Adjusted R^2 values in the Accumulated Degree Day Model. The p-values for statistical significance are displayed in red.

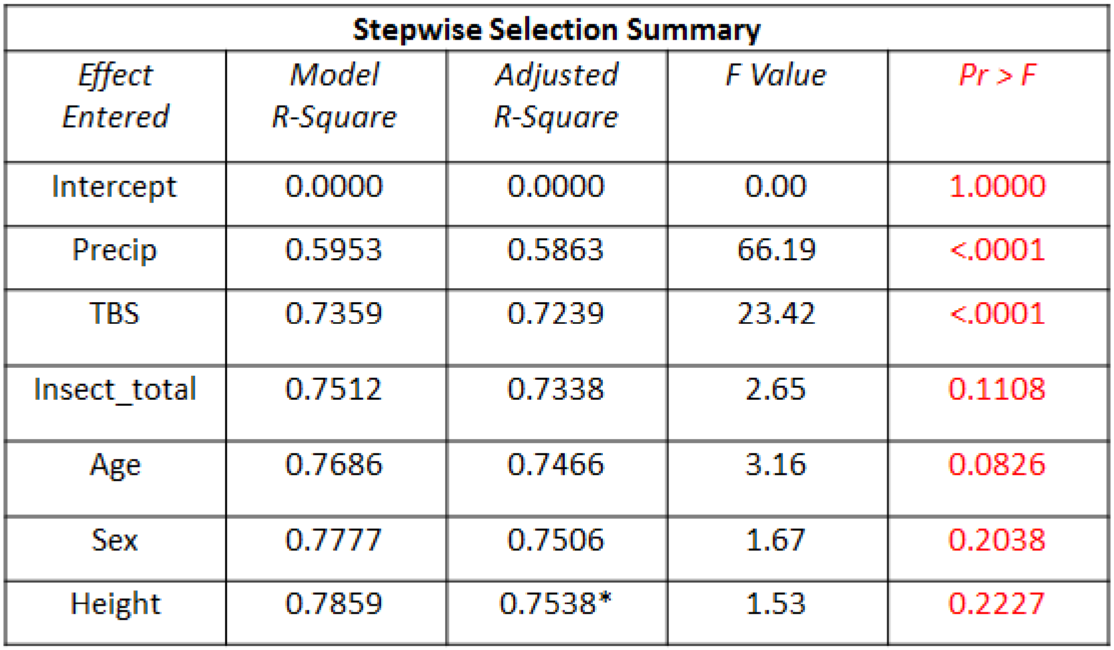


Stepwise Selection Summary

Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
TBS	0.5958	0.5870	67.79	<.0001
Body Position	0.6589	0.5992	1.04	0.4083
Decomp_case	0.6705	0.6029	1.37	0.2488
Clothing_Total	0.6733	0.6062*	1.25	0.3428

PMI Model: Covariate Selection

Table 31. Stepwise Selection Summary of Covariates with the Highest Adjusted R^2 values in the Post-Mortem Interval Day Model. The *p*-values for statistical significance are displayed in red.



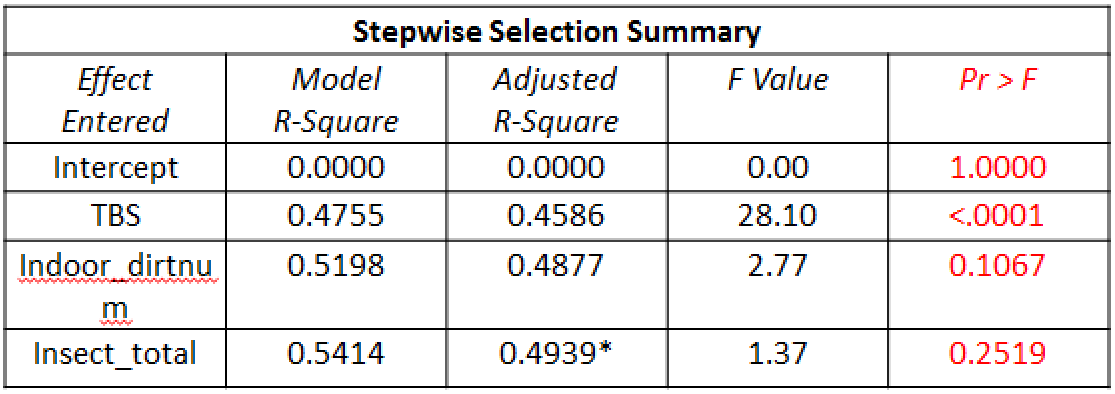
Stepwise Selection Summary

Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
Precip	0.5953	0.5863	66.19	<.0001
TBS	0.7359	0.7239	23.42	<.0001
Insect_total	0.7512	0.7338	2.65	0.1108
Age	0.7686	0.7466	3.16	0.0826
Sex	0.7777	0.7506	1.67	0.2038
Height	0.7859	0.7538*	1.53	0.2227

Stratified Analysis

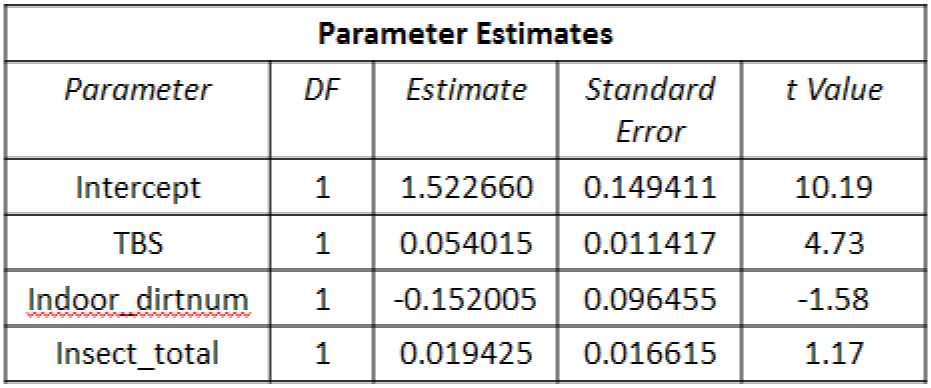
Indoor ADD Model: Covariate Selection

Table 32. Stepwise Selection Summary of Covariates with the Highest Adjusted R^2 values in the Indoor subset of the Accumulated Degree Day Model. The p-values for statistical significance are displayed in red.



Stepwise Selection Summary

Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
TBS	0.4755	0.4586	28.10	<.0001
Indoor_dirtnum	0.5198	0.4877	2.77	0.1067
Insect_total	0.5414	0.4939*	1.37	0.2519

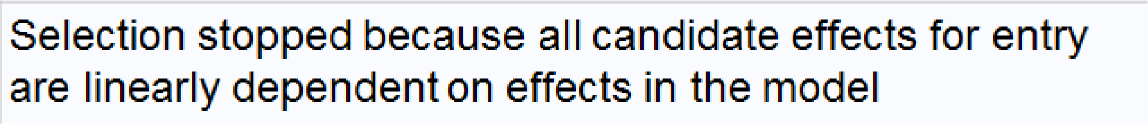


Parameter Estimates

Parameter	*DF*	*Estimate*	*Standard Error*	*t Value*
Intercept	1	1.522660	0.149411	10.19
TBS	1	0.054015	0.011417	4.73
Indoor_dirtnum	1	-0.152005	0.096455	-1.58
Insect_total	1	0.019425	0.016615	1.17

Non-Water Outdoor PMI Model: Covariate Selection

Table 33. Stepwise Selection Summary of Covariates with the Highest Adjusted R^2 values in the Non-Water Outdoor subset of the Post-Mortem Interval Day Model.



Selection stopped because all candidate effects for entry are linearly dependent on effects in the model

Rate of Decay

Rate of Decay per Depositional Context

Table 34. The Predicted Accumulated Degree Days per Total Body Score. From the TBS of 3 until 11, the indoor subset demonstrates the least amount of ADD required to produce each TBS. The outdoor subset is the slowest. However, past this point, the relationship switches, with the outdoor case demonstrating the fastest rate. The joint non-water outdoor and indoor subset demonstrates predicted ADD values between the outdoor and indoor estimates.

Total Body Score	**Outdoor**	**Indoor**	**Outdoor and Indoor**
3	49.11339996	37.53185	51.72494053
4	55.70574669	44.0352	58.80306995
5	63.18296467	51.66542	66.84978272
6	71.66382755	60.61778	75.99762144
7	81.28305162	71.12135	86.39726607
8	92.19343575	83.44494	98.22001588
9	104.5682885	97.9039	111.660611
10	118.6041813	114.8682	126.9404402
11	134.5240705	134.7721	144.3111874
12	152.5808395	158.1248	164.0589773
13	173.0613153	185.524	186.5090887
14	196.2908248	217.6707	212.0313117
15	222.638363	255.3877	241.0460394
16	252.5224533	299.6401	274.0311921
17	286.417797	351.5604	311.5300896
18	324.8628126	412.4772	354.1604004
19	368.4681891	483.9494	402.624316
20	417.9265867	567.806	457.7201167
21	474.023639	666.1929	520.3553211
22	537.6504331	781.6278	591.5616342
23	609.817664	917.0647	672.511941
24	691.6716893	1075.97	764.5396264
25	784.5127388	1262.409	869.1605379
26	889.8155684	1481.153	988.0979539
27	1009.252886	1737.801	1123.31097
28	1144.721922	2038.919	1277.026766
29	1298.374568	2392.214	1451.777295
30	1472.651554	2806.726	1650.440986
31	1670.321226	3293.063	1876.290156

32	1894.523514	3863.67	2133.044913
33	2148.819814	4533.149	2424.934431
34	2437.249556	5318.633	2756.76661
35	2764.394371	6240.221	3134.007273
36	3135.450869	7321.499	3562.870194
37	3556.313186	8590.135	4050.419451
38	4033.666609	10078.6	4604.685784
39	4575.093773	11824.97	5234.79887
40	5189.195108	13873.95	5951.13771
41	5885.725453	16277.96	6765.501583
42	6675.74901	19098.53	7691.304403

t-Test for Statistical Significance: Indoor vs. Non-Water Outdoor

Table 35. Two Sample t-Test Assuming Unequal Variances between Indoor and Non-Water Outdoor Cases. The t Stat value is higher than the t Crit values; indicating a statistically significant difference.

t-Test: Two-Sample Assuming Unequal Variances: Indoor vs Outdoor ALL		
	Indoor	***Outdoor***
Mean	3227.563778	1401.115083
Variance	23504398.16	3117946.994
Observations	40	40
Hypothesized Mean Difference	0	
Df	49	
t Stat	2.238794949	
P(T<=t) one-tail	0.014871835	
t Critical one-tail	1.676550893	
P(T<=t) two-tail	0.02974367	
t Critical two-tail	2.009575237	

t-Test for Statistical Significance: Indoor vs. Non-Water Outdoor and Indoor

Table 36. Two Sample t-Test Assuming Unequal Variances between Indoor and Non-Water Outdoor and Indoor Cases. The t Stat value is higher than the t Crit values, indicating a statistically significant difference.

t-Test: Two-Sample Assuming Unequal Variances		
	Indoor	***Outdoor and Indoor***
Mean	3227.563778	1587.979022
Variance	23504398.16	4117592.255
Observations	40	40
Hypothesized Mean Difference	0	
df	52	
t Stat	1.973042237	
P(T<=t) one-tail	0.02690859	
t Critical one-tail	1.674689154	
P(T<=t) two-tail	0.05381718	
t Critical two-tail	2.006646805	

Model Comparison: Megyesi versus Delaware River Valley

All Cases: Mean Predicted ADD Average and Standard Deviation versus Observed ADD Values

Table 37. The Average ADD and Standard Deviation for Observed Values, versus Average ADD and Standard Deviation for Predicted Values in All Cases using the Megyesi et al. (2005) and overall Delaware River Valley Equation. The averages and standard deviations are listed at the bottom of the table.

Case #	**Actual ADD**	**DRV Predicted ADD**	**Megyesi Predicted ADD**
1	650.278	494.704	447.198
6	2555	3321.085	3104.56
11	174.722	184.765	140.605
15	116.111	184.765	140.605
21	103.333	124.603	102.329
34	347.5	312.421	244.343
35	276.111	210.693	159.221
42	146.111	109.27	93.756
66	226.944	210.693	159.221
69	391.667	240.259	181.97
29	96.389	184.765	140.605
36	285	142.089	112.72
37	152.5	109.27	93.756
44	97.778	95.823	86.696
45	175	210.693	159.221
47	138.333	210.693	159.221
48	224.722	142.089	112.72
49	77.222	109.27	93.756
50	405.833	184.765	140.605
51	217.222	210.693	159.221
52	271.389	210.693	159.221
53	110.278	184.765	140.605
55	683.611	406.256	340.408
56	292.778	162.028	125.314
57	107.222	184.765	140.605
58	198.056	184.765	140.605
60	464.722	273.974	209.894
61	92.222	142.089	112.72

62	278.889	463.266	407.38
63	271.667	162.028	125.314
64	427.778	356.262	287.078
65	176.389	184.765	140.605
68	282.5	210.693	159.221
69	391.667	240.259	181.97
71	103.611	184.765	140.605
72	116.111	124.603	102.329
73	57.222	142.089	112.72
74	250	273.974	209.894
76	1327.778	602.407	599.791
77	222.5	273.974	209.894
78	45.278	162.028	125.314
79	578.611	602.407	599.791
80	541.389	463.266	407.38
5	2333.056	2912.393	3104.56
9	1245.833	1324.555	1853.532
10	120	124.603	102.329
12	848.889	312.421	244.343
13	1079.444	783.339	916.22
14	2838.889	5615.65	7221.074
17	3532.778	2912.393	4073.803
18	2215.556	2553.994	4073.803
22	965.833	1964.084	3104.56
23	1690.833	783.339	916.22
26	223.333	184.765	140.605
27	223.333	210.693	159.221
28	941.667	783.339	916.22
29	96.389	184.765	140.605
81	239.05	580.9751894	292.0583847
83	191.8055556	328.3764995	169.6291924
84	191.8055556	328.3764995	169.6291924
86	162.2	153.4586521	99.18470562
88	462.5	397.1615906	200.5998292
89	789.5	1027.881627	567.3830241
90	120.9	271.5044153	145.3774435
91	251.6	328.3764995	169.6291924
92	78.21294444	328.3764995	169.6291924
93	82.57	185.6036667	111.1652591
94	47.90222222	271.5044153	145.3774435

96	146.0412222	185.6036667	111.1652591
97	173.3101667	328.3764995	169.6291924
98	109.8848889	271.5044153	145.3774435
99	84.10216667	271.5044153	145.3774435
101	1138.85	1367.212002	827.4538051
104	108.4026667	224.482104	126.2757211
105	208.9	271.5044153	145.3774435
110	122.7288889	224.482104	126.2757211
114	189.8	185.6036667	111.1652591
115	112.5	271.5044153	145.3774435
117	54.53327778	271.5044153	145.3774435
124	99	397.1615906	200.5998292
Average:	**470.8922069**	**528.8987658**	**535.2149608**
Standard Deviation:	**674.0655285**	**865.6399457**	**1131.718112**

All Cases: Average Predicted versus Observed Value Differential

Table 38. The Average ADD Differential of Predicted versus Observed Values in All Cases using the Megyesi et al. (2005) and overall Delaware River Valley Equation. The averages are listed at the bottom of the table.

Case #	DRV Predicted ADD Differential	Megyesi Predicted ADD Differential
1	-155.574	-203.08
6	766.085	549.56
11	10.043	-34.117
15	68.654	24.494
21	21.27	-1.004
34	-35.079	-103.157
35	-65.418	-116.89
42	-36.841	-52.355
66	-16.251	-67.723
69	-151.408	-209.697
29	88.376	44.216
36	-142.911	-172.28
37	-43.23	-58.744
44	-1.955	-11.082
45	35.693	-15.779
47	72.36	20.888
48	-82.633	-112.002
49	32.048	16.534
50	-221.068	-265.228
51	-6.529	-58.001
52	-60.696	-112.168
53	74.487	30.327
55	-277.355	-343.203
56	-130.75	-167.464
57	77.543	33.383
58	-13.291	-57.451
60	-190.748	-254.828
61	49.867	20.498
62	184.377	128.491
63	-109.639	-146.353
64	-71.516	-140.7
65	8.376	-35.784
68	-71.807	-123.279

69	-151.408	-209.697
71	81.154	36.994
72	8.492	-13.782
73	84.867	55.498
74	23.974	-40.106
76	-725.371	-727.987
77	51.474	-12.606
78	116.75	80.036
79	23.796	21.18
80	-78.123	-134.009
5	579.337	771.504
9	78.722	607.699
10	4.603	-17.671
12	-536.468	-604.546
13	-296.105	-163.224
14	2776.761	4382.185
17	-620.385	541.025
18	338.438	1858.247
22	998.251	2138.727
23	-907.494	-774.613
26	-38.568	-82.728
27	-12.64	-64.112
28	-158.328	-25.447
29	88.376	44.216
81	341.9251894	53.00838473
83	136.5709439	-22.17636312
84	136.5709439	-22.17636312
86	-8.741347885	-63.01529438
88	-65.33840937	-261.9001708
89	238.3816274	-222.1169759
90	150.6044153	24.47744348
91	76.7764995	-81.97080756
92	250.1635551	91.416248
93	103.0336667	28.59525906
94	223.602193	97.47522126
96	39.56244452	-34.87596314
97	155.0663328	-3.680974259
98	161.6195264	35.49255458
99	187.4022486	61.27527681
101	228.3620017	-311.3961949

104	116.0794373	17.87305442
105	62.60441525	-63.52255652
110	101.7532151	3.546832222
114	-4.196333285	-78.63474094
115	159.0044153	32.87744348
117	216.9711375	90.8441657
124	298.1615906	101.5998292
Average:	**58.00655886**	**64.32275385**

All Cases: Average Predicted versus Observed Absolute Value Differential

Table 39. The Average ADD Absolute Value Differential of Predicted versus Observed Values in All Cases using the Megyesi et al. (2005) and overall Delaware River Valley Equation. The averages are listed at the bottom of the table.

Case #	DRV Average Predicted Absolute Value Differential	Megyesi Average Predicted Absolute Value Differential
1	155.574	203.08
6	766.085	549.56
11	10.043	34.117
15	68.654	24.494
21	21.27	1.004
34	35.079	103.157
35	65.418	116.89
42	36.841	52.355
66	16.251	67.723
69	151.408	209.697
29	88.376	44.216
36	142.911	172.28
37	43.23	58.744
44	1.955	11.082
45	35.693	15.779
47	72.36	20.888
48	82.633	112.002
49	32.048	16.534
50	221.068	265.228
51	6.529	58.001
52	60.696	112.168
53	74.487	30.327
55	277.355	343.203
56	130.75	167.464
57	77.543	33.383
58	13.291	57.451
60	190.748	254.828
61	49.867	20.498
62	184.377	128.491
63	109.639	146.353
64	71.516	140.7
65	8.376	35.784
68	71.807	123.279

69	151.408	209.697
71	81.154	36.994
72	8.492	13.782
73	84.867	55.498
74	23.974	40.106
76	725.371	727.987
77	51.474	12.606
78	116.75	80.036
79	23.796	21.18
80	78.123	134.009
5	579.337	771.504
9	78.722	607.699
10	4.603	17.671
12	536.468	604.546
13	296.105	163.224
14	2776.761	4382.185
17	620.385	541.025
18	338.438	1858.247
22	998.251	2138.727
23	907.494	774.613
26	38.568	82.728
27	12.64	64.112
28	158.328	25.447
29	88.376	44.216
81	341.9251894	53.00838473
83	136.5709439	22.17636312
84	136.5709439	22.17636312
86	8.741347885	63.01529438
88	65.33840937	261.9001708
89	238.3816274	222.1169759
90	150.6044153	24.47744348
91	76.7764995	81.97080756
92	250.1635551	91.416248
93	103.0336667	28.59525906
94	223.602193	97.47522126
96	39.56244452	34.87596314
97	155.0663328	3.680974259
98	161.6195264	35.49255458
99	187.4022486	61.27527681
101	228.3620017	311.3961949

104	116.0794373	17.87305442
105	62.60441525	63.52255652
110	101.7532151	3.546832222
114	4.196333285	78.63474094
115	159.0044153	32.87744348
117	216.9711375	90.8441657
124	298.1615906	101.5998292
Average:	**195.2031861**	**236.781839**

Outdoor/Indoor: Mean Predicted ADD Average and Standard Deviation versus Observed ADD Values

Table 40. The Average ADD and Standard Deviation for Observed Values, versus Average ADD and Standard Deviation for Predicted Values in Non-Water Outdoor and Indoor Cases using the Megyesi et al. (2005) and the non-water outdoor and indoor Delaware River Valley Equations. The averages and standard deviations are listed at the bottom of the table.

Case	**Actual ADD (Celsius)**	**DRV Predicted ADD**	**Megyesi Predicted ADD**
1	650.278	488.033911	447.198
6	2555	3134.007273	3104.56
11	174.722	186.5090887	140.605
15	116.111	186.5090887	140.605
21	103.333	126.9404402	102.329
34	347.5	311.5300896	244.343
35	276.111	212.0313117	159.221
42	146.111	111.660611	93.756
66	226.944	212.0313117	159.221
69	391.667	241.0460394	181.97
29	96.389	186.5090887	140.605
36	285	144.3111874	112.72
37	152.5	111.660611	93.756
44	97.778	98.22001588	86.696
45	175	212.0313117	159.221
47	138.333	212.0313117	159.221
48	224.722	144.3111874	112.72
49	77.222	111.660611	93.756
50	405.833	186.5090887	140.605
51	217.222	212.0313117	159.221
52	271.389	212.0313117	159.221
53	110.278	186.5090887	140.605
55	683.611	402.624316	340.408
56	292.778	164.0589773	125.314
57	107.222	186.5090887	140.605
58	198.056	186.5090887	140.605
60	464.722	274.0311921	209.894
61	92.222	144.3111874	112.72
62	278.889	457.7201167	407.38

63	271.667	164.0589773	125.314
64	427.778	354.1604004	287.078
65	176.389	186.5090887	140.605
68	282.5	212.0313117	159.221
69	391.667	241.0460394	181.97
71	103.611	186.5090887	140.605
72	116.111	126.9404402	102.329
73	57.222	144.3111874	112.72
74	250	274.0311921	209.894
76	1327.778	591.5616342	599.791
77	222.5	274.0311921	209.894
78	45.278	164.0589773	125.314
79	578.611	591.5616342	599.791
80	541.389	457.7201167	407.38
5	2333.056	2756.76661	3104.56
9	1245.833	1277.026766	1853.532
10	120	126.9404402	102.329
12	848.889	311.5300896	244.343
13	1079.444	764.5396264	916.22
14	2838.889	5234.79887	7221.074
17	3532.778	2756.76661	4073.803
18	2215.556	2424.934431	4073.803
22	965.833	1876.290156	3104.56
23	1690.833	764.5396264	916.22
26	223.333	186.5090887	140.605
27	223.333	212.0313117	159.221
28	941.667	764.5396264	916.22
29	96.389	186.5090887	140.605
Average ADD	**570.2680175**	**572.9146119**	**669.7909123**
Std Dev	**761.9338975**	**941.9067828**	**1316.001524**

Outdoor/Indoor: Average Predicted versus Observed Value Differential

Table 41. The Average ADD Differential of Predicted versus Observed Values in Non-Water Outdoor and Indoor Cases using the Megyesi et al. (2005) and the non-water outdoor and indoor Delaware River Valley Equations. The averages are listed at the bottom of the table.

Case	DRV Predicted Differential	Megyesi Predicted Differential
1	-162.244089	-203.08
6	579.0072731	549.56
11	11.78708866	-34.117
15	70.39808866	24.494
21	23.6074402	-1.004
34	-35.9699104	-103.157
35	-64.07968833	-116.89
42	-34.45038899	-52.355
66	-14.91268833	-67.723
69	-150.6209606	-209.697
29	90.12008866	44.216
36	-140.6888126	-172.28
37	-40.83938899	-58.744
44	0.442015877	-11.082
45	37.03131167	-15.779
47	73.69831167	20.888
48	-80.41081263	-112.002
49	34.43861101	16.534
50	-219.3239113	-265.228
51	-5.190688326	-58.001
52	-59.35768833	-112.168
53	76.23108866	30.327
55	-280.986684	-343.203
56	-128.7190227	-167.464
57	79.28708866	33.383
58	-11.54691134	-57.451
60	-190.6908079	-254.828
61	52.08918737	20.498
62	178.8311167	128.491
63	-107.6080227	-146.353
64	-73.61759957	-140.7
65	10.12008866	-35.784
68	-70.46868833	-123.279

69	-150.6209606	-209.697
71	82.89808866	36.994
72	10.8294402	-13.782
73	87.08918737	55.498
74	24.0311921	-40.106
76	-736.2163658	-727.987
77	51.5311921	-12.606
78	118.7809773	80.036
79	12.95063418	21.18
80	-83.66888329	-134.009
5	423.7106103	771.504
9	31.19376598	607.699
10	6.940440196	-17.671
12	-537.3589104	-604.546
13	-314.9043736	-163.224
14	2395.90987	4382.185
17	-776.0113897	541.025
18	209.378431	1858.247
22	910.4571558	2138.727
23	-926.2933736	-774.613
26	-36.82391134	-82.728
27	-11.30168833	-64.112
28	-177.1273736	-25.447
29	90.12008866	44.216
Average Differential	**2.646594367**	**99.52289474**
Std Dev	**422.1436409**	**736.5576306**

Outdoor/Indoor: Average Predicted versus Observed Absolute Value Differential

Table 42. The Average ADD Absolute Value Differential of Predicted versus Observed Values in Non-Water Outdoor and Indoor Cases using the Megyesi et al. (2005) and the non-water outdoor and indoor Delaware River Valley Equations. The averages are listed at the bottom of the table.

Case	DRV Average Predicted Absolute Value Differential	Megyesi Average Predicted Absolute Value Differential
1	162.244089	203.08
6	579.0072731	549.56
11	11.78708866	34.117
15	70.39808866	24.494
21	23.6074402	1.004
34	35.9699104	103.157
35	64.07968833	116.89
42	34.45038899	52.355
66	14.91268833	67.723
69	150.6209606	209.697
29	90.12008866	44.216
36	140.6888126	172.28
37	40.83938899	58.744
44	0.442015877	11.082
45	37.03131167	15.779
47	73.69831167	20.888
48	80.41081263	112.002
49	34.43861101	16.534
50	219.3239113	265.228
51	5.190688326	58.001
52	59.35768833	112.168
53	76.23108866	30.327
55	280.986684	343.203
56	128.7190227	167.464
57	79.28708866	33.383
58	11.54691134	57.451
60	190.6908079	254.828
61	52.08918737	20.498
62	178.8311167	128.491
63	107.6080227	146.353
64	73.61759957	140.7
65	10.12008866	35.784

68	70.46868833	123.279
69	150.6209606	209.697
71	82.89808866	36.994
72	10.8294402	13.782
73	87.08918737	55.498
74	24.0311921	40.106
76	736.2163658	727.987
77	51.5311921	12.606
78	118.7809773	80.036
79	12.95063418	21.18
80	83.66888329	134.009
5	423.7106103	771.504
9	31.19376598	607.699
10	6.940440196	17.671
12	537.3589104	604.546
13	314.9043736	163.224
14	2395.90987	4382.185
17	776.0113897	541.025
18	209.378431	1858.247
22	910.4571558	2138.727
23	926.2933736	774.613
26	36.82391134	82.728
27	11.30168833	64.112
28	177.1273736	25.447
29	90.12008866	44.216
Average Abs. Val. Differential	**199.9116468**	**300.6771754**
Std Dev	**370.8558504**	**678.6587147**

Confidence Interval Forecasting

Overall Equation

Table 43. 95% Confidence Interval Forecasting Using Each Total Body Score for the Overall Equation.

TBS	Lower Limit	Overall Model	Upper Limit
3	-106.904095	49.6958359	206.295767
4	-94.6527122	56.66958079	207.9918738
5	-81.5247864	64.62194123	210.7686688
6	-67.3942238	73.69024493	214.7747136
7	-52.1170652	84.03109058	220.1792463
8	-35.5289368	95.82305218	227.1750412
9	-17.4421207	109.2697627	235.9816461
10	2.357819537	124.6034307	246.8490419
11	24.11593295	142.0888502	260.0617675
12	48.11238776	162.0279734	275.943559
13	74.66769634	184.7651249	294.8625535
14	104.1487854	210.6929481	317.2371108
15	136.9760545	240.2591853	343.542316
16	173.631581	273.9744098	374.3172386
17	214.6686402	312.4208431	410.1730459
18	260.7227064	356.2624088	451.8021112
19	312.5240906	406.2561982	499.9883057
20	370.9123472	463.2655438	555.6187404

21	**436.8525596**	**528.2749286**	**619.6972976**
22	**511.4536036**	**602.4069865**	**693.3603694**
23	**595.9885061**	**686.941889**	**777.8952719**
24	**691.9170833**	**783.3394523**	**874.7618213**
25	**800.9111498**	**893.2643464**	**985.617543**
26	**924.8827347**	**1018.614842**	**1112.34695**
27	**1066.01589**	**1161.555592**	**1257.095295**
28	**1226.802808**	**1324.555011**	**1422.307214**
29	**1410.085074**	**1510.427903**	**1610.770732**
30	**1619.100939**	**1722.384069**	**1825.6672**
31	**1857.539576**	**1964.083739**	**2070.627901**
32	**2129.603345**	**2239.700774**	**2349.798202**
33	**2440.079163**	**2553.994749**	**2667.910335**
34	**2794.420227**	**2912.393144**	**3030.366061**
35	**3198.839457**	**3321.085068**	**3443.330679**
36	**3660.416257**	**3787.12814**	**3913.840023**
37	**4187.218374**	**4318.570363**	**4449.922352**
38	**4788.44095**	**4924.589106**	**5060.737261**
39	**5474.565115**	**5615.649584**	**5756.734052**
40	**6257.538853**	**6403.68558**	**6549.832308**
41	**7150.983238**	**7302.305531**	**7453.627824**
42	**8170.42759**	**8327.027521**	**8483.627452**

Outdoor/Indoor Equation

Table 44. 95% Confidence Interval Forecasting Using Each Total Body Score for the Outdoor and Indoor Equation.

TBS	Lower Limit	Out/In Model	Upper Limit
3	-141.035	51.72494	244.4846
4	-127.532	58.80307	245.138
5	-113.187	66.84978	246.8868
6	-97.882	75.99762	249.8773
7	-81.481	86.39727	254.2755
8	-63.8303	98.22002	260.2703
9	-44.7544	111.6606	268.0756
10	-24.0536	126.9404	277.9345
11	-1.50017	144.3112	290.1225
12	23.16583	164.059	304.9521
13	50.24098	186.5091	322.7772
14	80.06426	212.0313	343.9984
15	113.0234	241.046	369.0687
16	149.5624	274.0312	398.5
17	190.1903	311.5301	432.8699
18	235.4911	354.1604	472.8297
19	286.1355	402.6243	519.1132
20	342.8938	457.7201	572.5465
21	406.6508	520.3553	634.0598

22	**478.4222**	**591.5616**	**704.701**
23	**559.3725**	**672.5119**	**785.6513**
24	**650.8351**	**764.5396**	**878.2441**
25	**754.3342**	**869.1605**	**983.9869**
26	**871.6091**	**988.098**	**1104.587**
27	**1004.642**	**1123.311**	**1241.98**
28	**1155.687**	**1277.027**	**1398.367**
29	**1327.309**	**1451.777**	**1576.246**
30	**1522.418**	**1650.441**	**1778.464**
31	**1744.323**	**1876.29**	**2008.257**
32	**1996.777**	**2133.045**	**2269.313**
33	**2284.041**	**2424.934**	**2565.828**
34	**2610.955**	**2756.767**	**2902.578**
35	**2983.013**	**3134.007**	**3285.001**
36	**3406.455**	**3562.87**	**3719.285**
37	**3888.369**	**4050.419**	**4212.47**
38	**4436.808**	**4604.686**	**4772.564**
39	**5060.919**	**5234.799**	**5408.679**
40	**5771.101**	**5951.138**	**6131.175**
41	**6579.167**	**6765.502**	**6951.837**

42	**7498.545**	**7691.304**	**7884.064**

Prediction Interval Forecasting

Overall Equation

Table 45. Prediction Interval Forecasting Using Each Total Body Score for the Overall Equation.

TBS	Lower Limit	Overall	Upper Limit
3	-778.2351096	49.6958359	877.6267814
4	-770.2793586	56.66958079	883.6185202
5	-761.3955998	64.62194123	890.6394823
6	-751.4466767	73.69024493	898.8271665
7	-740.2761533	84.03109058	908.3383345
8	-727.7056098	95.82305218	919.3517142
9	-713.5315581	109.2697627	932.0710835
10	-697.5219256	124.6034307	946.7287871
11	-679.4120453	142.0888502	963.5897457
12	-658.9000824	162.0279734	982.9560292
13	-635.6418204	184.7651249	1005.17207
14	-609.2447146	210.6929481	1030.630611
15	-579.2611117	240.2591853	1059.779482
16	-545.1805178	273.9744098	1093.129337
17	-506.420781	312.4208431	1131.262467
18	-462.3180373	356.2624088	1174.842855
19	-412.1152456	406.2561982	1224.627642
20	-354.9491132	463.2655438	1281.480201

21	**-289.8351872**	**528.2749286**	**1346.385044**
22	**-215.6508537**	**602.4069865**	**1420.464827**
23	**-131.1159512**	**686.941889**	**1504.999729**
24	**-34.77066355**	**783.3394523**	**1601.449568**
25	**75.04968939**	**893.2643464**	**1711.479003**
26	**200.2433984**	**1018.614842**	**1836.986286**
27	**342.975146**	**1161.555592**	**1980.136038**
28	**505.713387**	**1324.555011**	**2143.396635**
29	**691.2729754**	**1510.427903**	**2329.582831**
30	**902.8637725**	**1722.384069**	**2541.904366**
31	**1144.146076**	**1964.083739**	**2784.021401**
32	**1419.293828**	**2239.700774**	**3060.107719**
33	**1733.066693**	**2553.994749**	**3374.922805**
34	**2090.892248**	**2912.393144**	**3733.894039**
35	**2498.959712**	**3321.085068**	**4143.210424**
36	**2964.326819**	**3787.12814**	**4609.929461**
37	**3495.041701**	**4318.570363**	**5142.099025**
38	**4100.281862**	**4924.589106**	**5748.89635**
39	**4790.512662**	**5615.649584**	**6440.786505**
40	**5577.668039**	**6403.68558**	**7229.703121**
41	**6475.356591**	**7302.305531**	**8129.25447**
42	**7499.096575**	**8327.027521**	**9154.958466**

Outdoor/Indoor Equation

Table 46. Prediction Interval Forecasting Using Each Total Body Score for the Outdoor/Indoor Equation.

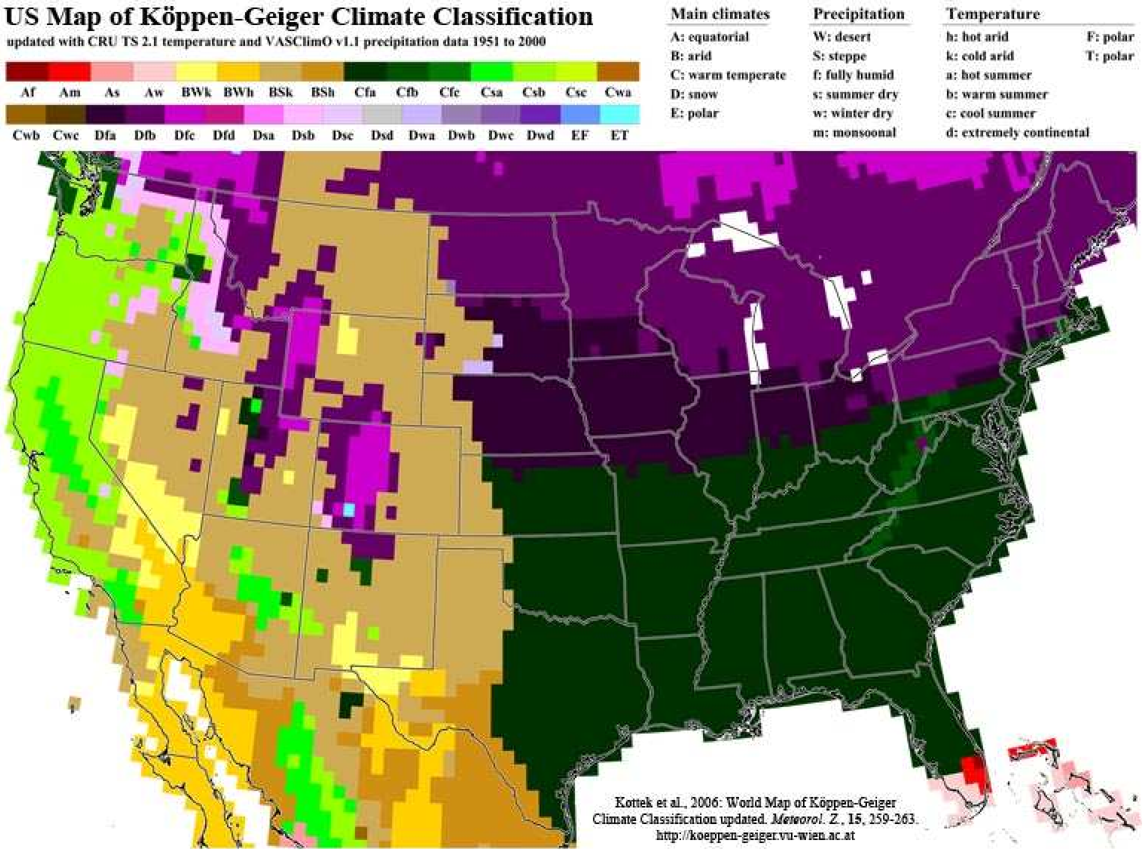
TBS	Lower Prediction Limit	Out/In Model	Upper Prediction Limit
3	-823.4166903	51.72494053	926.8665714
4	-814.9459197	58.80306995	932.5520596
5	-805.577812	66.84978272	939.2773775
6	-795.1801489	75.99762144	947.1753918
7	-783.6025587	86.39726607	956.3970909
8	-770.6740347	98.22001588	967.1140665
9	-756.2001125	111.660611	979.5213345
10	-739.9596624	126.9404402	993.8405428
11	-721.7012425	144.3111874	1010.323617
12	-701.1389524	164.0589773	1029.256907
13	-677.9477205	186.5090887	1050.965898
14	-651.7579453	212.0313117	1075.820569
15	-622.1494045	241.0460394	1104.241483
16	-588.64433	274.0311921	1136.706714
17	-550.6995358	311.5300896	1173.759715
18	-507.6974681	354.1604004	1216.018269
19	-458.9360316	402.624316	1264.184664
20	-403.6170227	457.7201167	1319.057256
21	-340.8329806	520.3553211	1381.543623

22	-269.5522392	591.5616342	1452.675508
23	-188.6019323	672.511941	1533.625814
24	-96.64867536	764.5396264	1625.727928
25	7.823398491	869.1605379	1730.497677
26	126.5376064	988.0979539	1849.658301
27	261.4531012	1123.31097	1985.168838
28	414.7971406	1277.026766	2139.256391
29	589.1017729	1451.777295	2314.452817
30	787.2455417	1650.440986	2513.63643
31	1012.500899	1876.290156	2740.079413
32	1268.588104	2133.044913	2997.501722
33	1559.736501	2424.934431	3290.132361
34	1890.75418	2756.76661	3622.77904
35	2267.10717	3134.007273	4000.907376
36	2695.009471	3562.870194	4430.730918
37	3181.525401	4050.419451	4919.313502
38	3734.685959	4604.685784	5474.685609
39	4363.6211	5234.79887	6105.97664
40	5078.710115	5951.13771	6823.565305
41	5891.752593	6765.501583	7639.250573
42	6816.162772	7691.304403	8566.446034

Appendix B: Figures

Köppen-Geiger Classification System

Figure 1. Climate Map of the United States based on Köppen-Geiger Classification System (Adapted from Kottek et al. 2006)

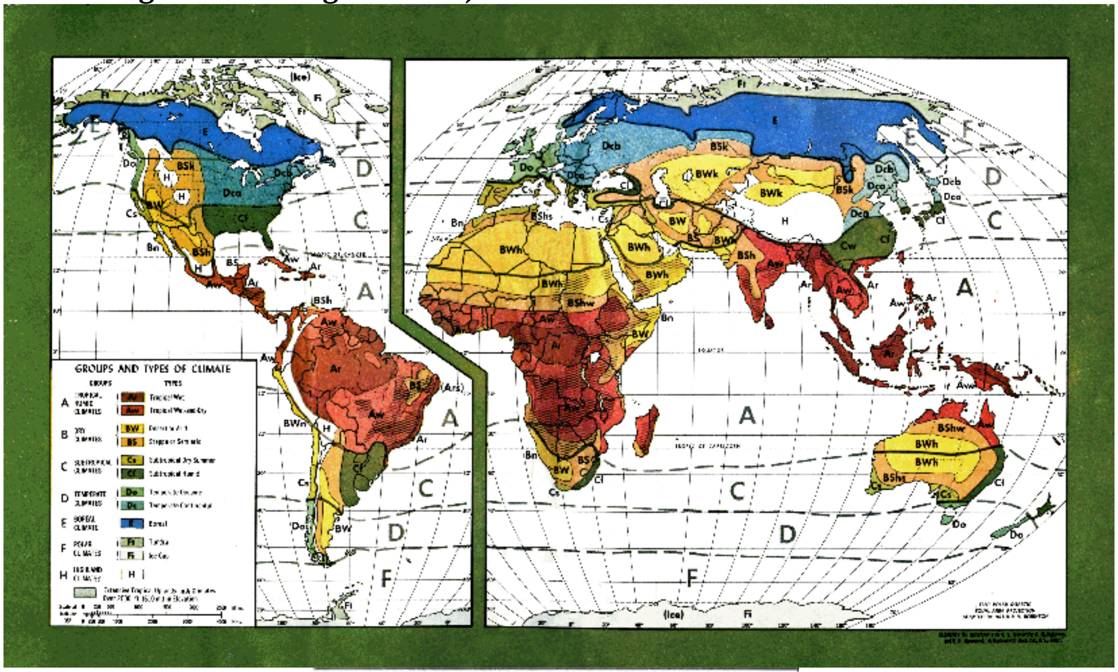


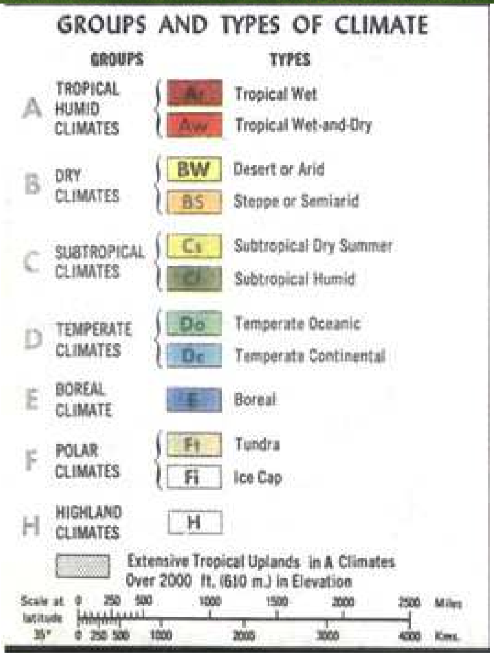
Kottek et al., 2006: World Map of Köppen-Geiger Climate Classification updated. *Meteorol. Z.*, 15, 259-263.
http://koeppen-geiger.vu-wien.ac.at

Köppen-Trewartha Classification System

<u>Global Climate Map</u>

Figure 2. Global Climate Map based on Köppen-Trewartha Classification System (Adapted from the Food Resources Assessment Programme of the United Nations Food and Agriculture Organization)





GROUPS AND TYPES OF CLIMATE

	GROUPS		TYPES
A	TROPICAL HUMID CLIMATES	Ar	Tropical Wet
		Aw	Tropical Wet-and-Dry
B	DRY CLIMATES	BW	Desert or Arid
		BS	Steppe or Semiarid
C	SUBTROPICAL CLIMATES	Cs	Subtropical Dry Summer
		Cf	Subtropical Humid
D	TEMPERATE CLIMATES	Do	Temperate Oceanic
		Dc	Temperate Continental
E	BOREAL CLIMATE	E	Boreal
F	POLAR CLIMATES	Ft	Tundra
		Fi	Ice Cap
H	HIGHLAND CLIMATES	H	

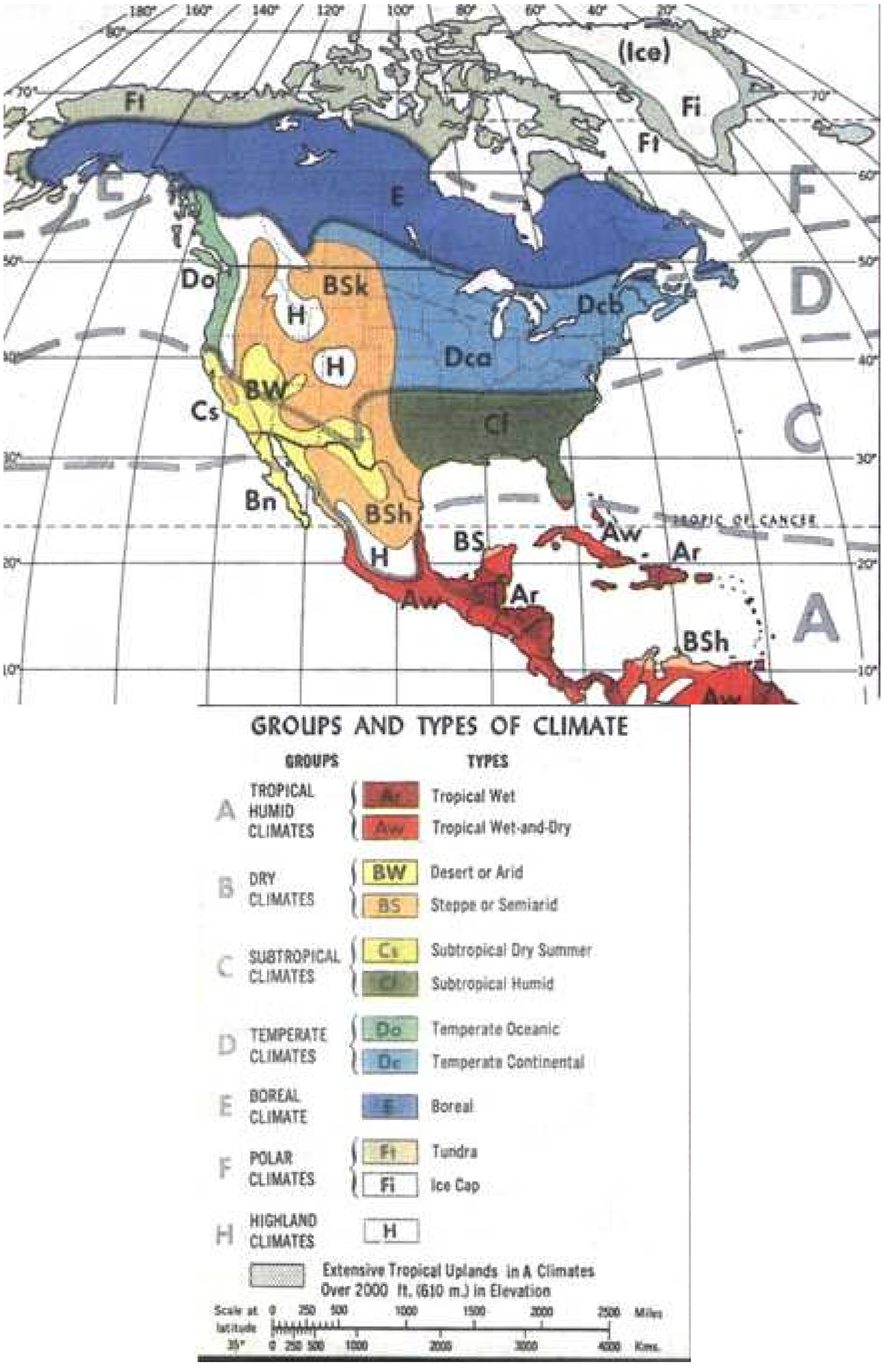
▨ Extensive Tropical Uplands in A Climates Over 2000 ft. (610 m.) in Elevation

Scale at latitude 35° 0 250 500 1000 1500 2000 2500 Miles

0 250 500 1000 2000 3000 4000 Kms.

United States Climate Map

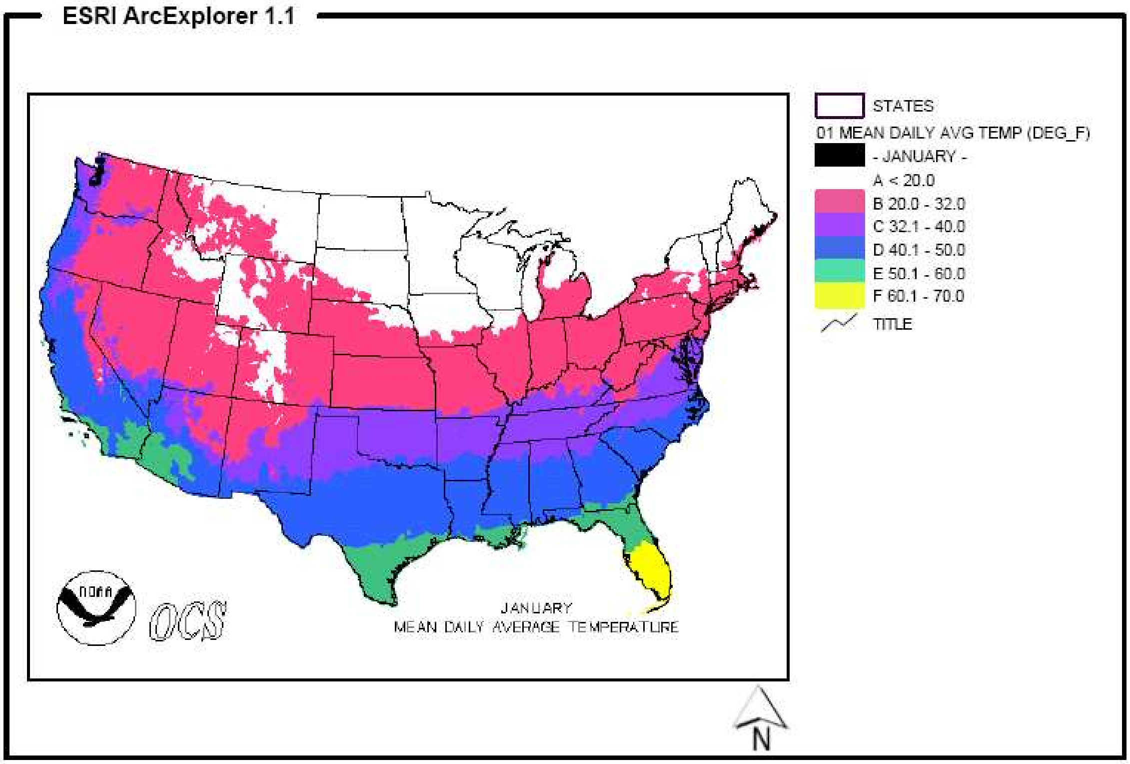
Figure 3. Climate Map of the United States Based on the Köppen-Trewartha Classification System (Adapted from the Food Resources Assessment Programme of the United Nations Food and Agriculture Organization)



Mean Daily Temperatures by Month

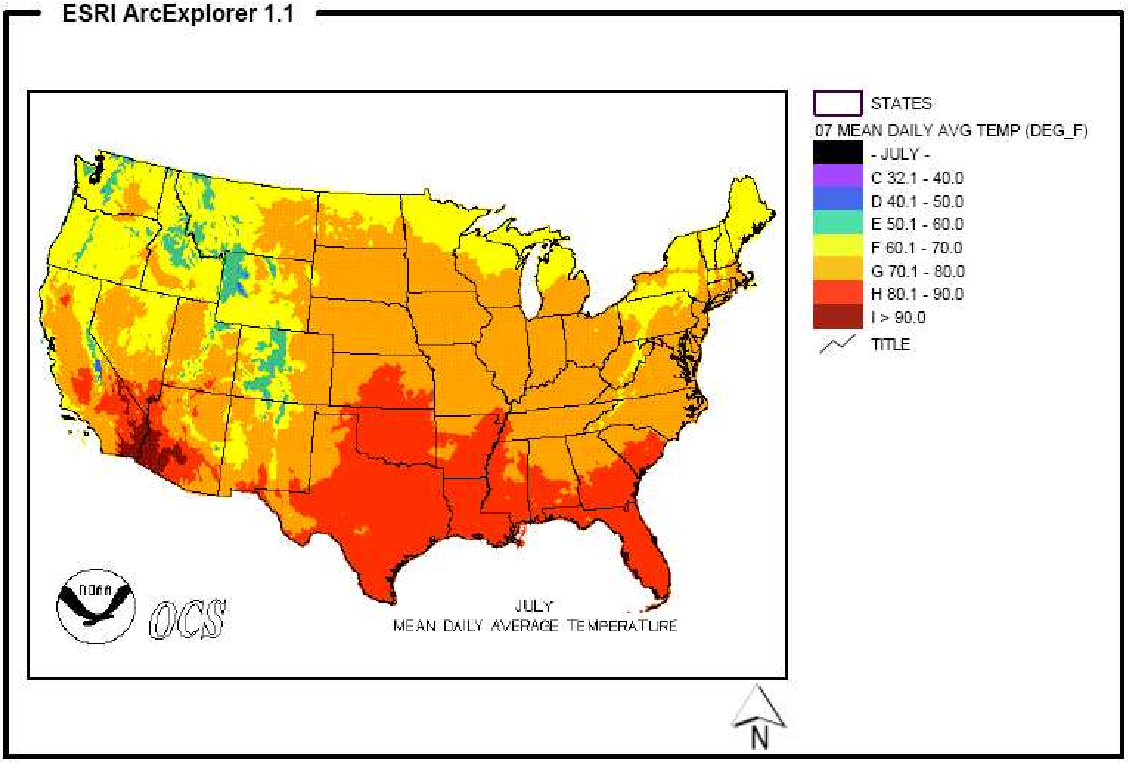
Mean Daily Temperatures in January in the United States

Figure 4. Mean Daily Temperatures in January for the continental United States, measured in degrees F. New Castle County falls within the mean daily temperature range of 20-32 degrees F, represented in pink. Kent and Sussex Counties fall within the mean daily temperature range of 32.1-40 degrees F, represented in purple (Adapted from the National Oceanic and Atmospheric Administration's National Climatic Data Center).



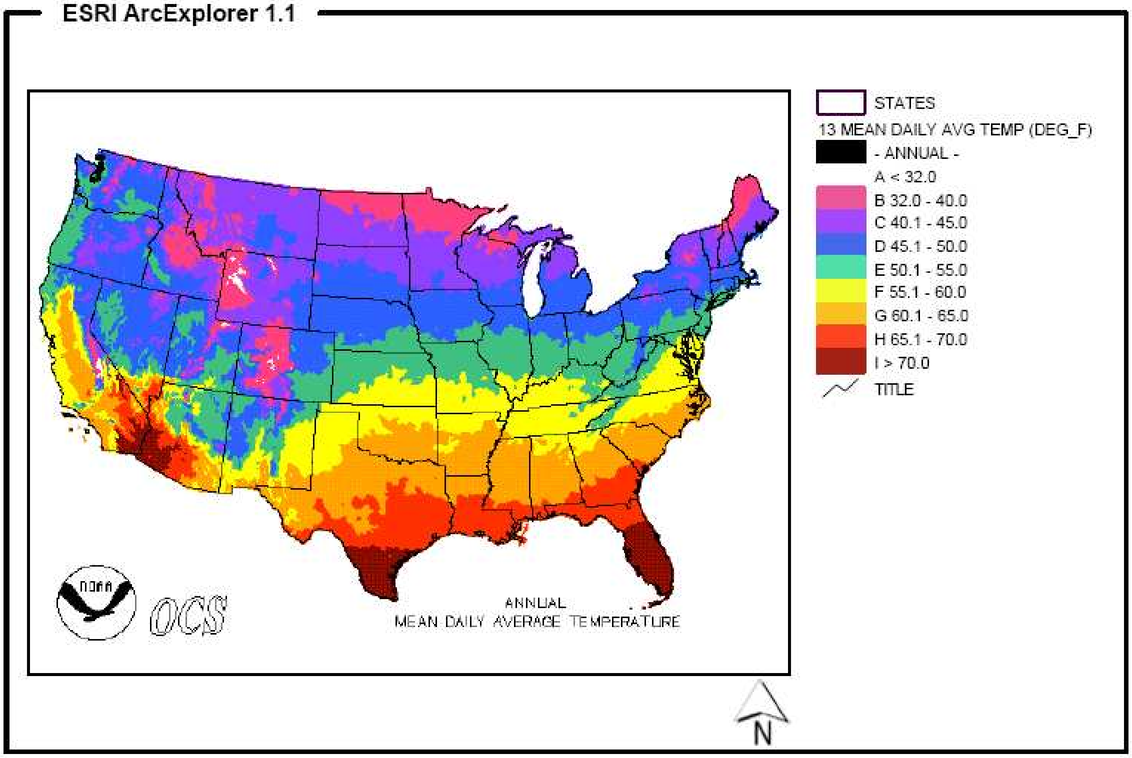
Mean Daily Temperatures in July in the United States

Figure 5. Mean Daily Temperatures in July for the continental United States, measured in degrees F. All three Counties fall within the mean daily temperature range of 70.1-80 degrees F, represented in orange (Adapted from the National Oceanic and Atmospheric Administration's National Climatic Data Center).



Mean Daily Temperatures Annually in the United States

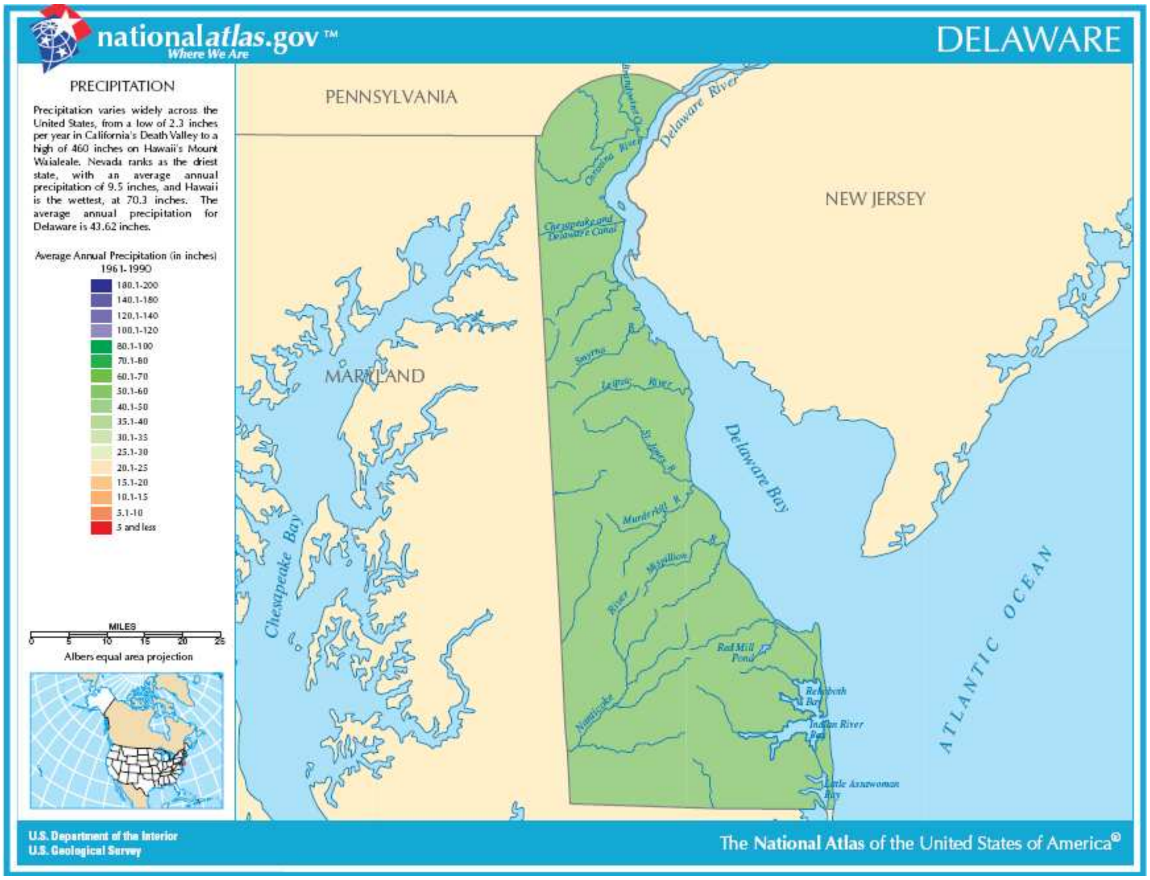
Figure 6. Mean Daily Temperatures Annually for the continental United States, measured in degrees F. New Castle County falls within the mean daily temperature range of 50.1-55 degrees F, represented in light green. Kent and Sussex Counties fall within the mean daily temperature range of 55.1-60 degrees F, represented in yellow (Adapted from the National Oceanic and Atmospheric Administration's National Climatic Data Center).



Average Annual Precipitation

<u>Average Annual Precipitation in Delaware</u>

Figure 7. Average annual precipitation in Delaware measured in inches and recorded from 1961-1990. The average annual precipitation for Delaware is 43.62 inches, with an average range between 40.1-50 inches per year (Adapted from the U.S. Department of the Interior/U.S. Geological Survey).

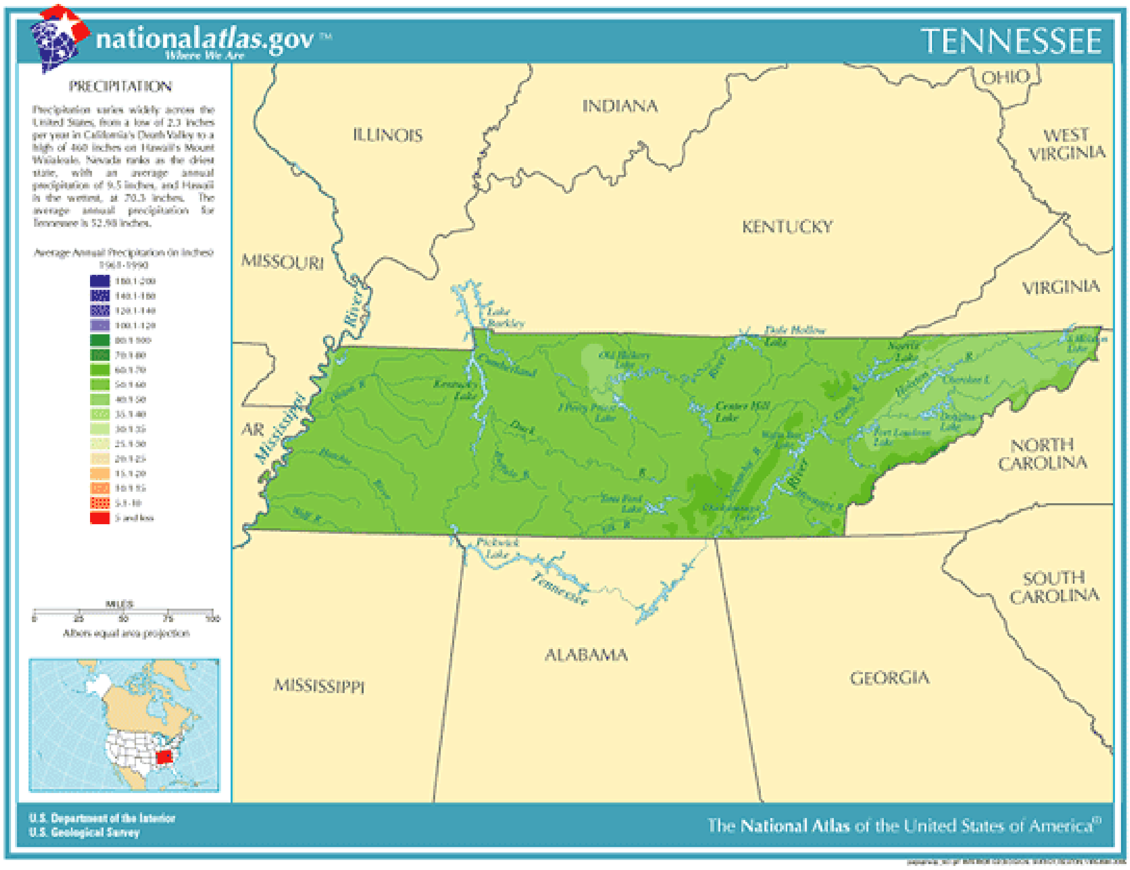


PRECIPITATION

Precipitation varies widely across the United States, from a low of 2.3 inches per year in California's Death Valley to a high of 460 inches on Hawaii's Mount Waialeale. Nevada ranks as the driest state, with an average annual precipitation of 9.5 inches, and Hawaii is the wettest, at 70.3 inches. The average annual precipitation for Delaware is 43.62 inches.

Average Annual Precipitation in Tennessee

Figure 8. Average annual precipitation in Tennessee measured in inches and recorded from 1961-1990. The average annual precipitation for Tennessee is 52.98 inches, with an average range between 50.1-60 inches per year (Adapted from the U.S. Department of the Interior/U.S. Geological Survey).

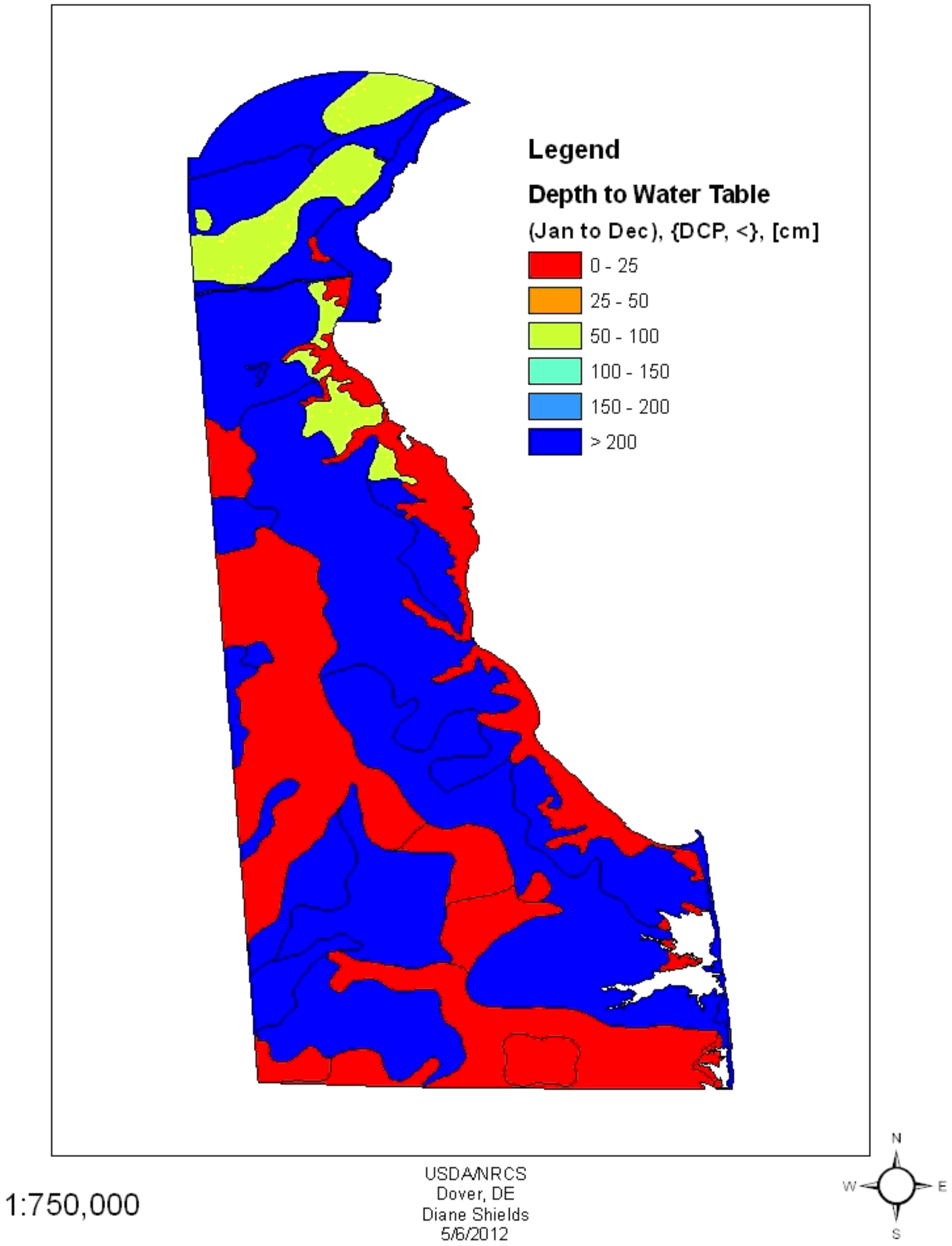


PRECIPITATION

Precipitation varies widely across the United States, from a low of 2.3 inches per year in California's Death Valley to a high of 460 inches on Hawaii's Mount Waialeale. Nevada ranks as the driest state, with an average annual precipitation of 9.5 inches, and Hawaii is the wettest, at 70.3 inches. The average annual precipitation for Tennessee is 52.98 inches.

Depth to Water Table in Delaware

Figure 9. Depth to Water Table in Delaware from January to December, measured in centimeters. The depth of the water table is a significant feature of many of the Coastal Plain soils and can have significance in regards to the decay rate, especially in regards to adipocere formation (Adapted from the United States Department of Agriculture/National Resources Conservation Service).



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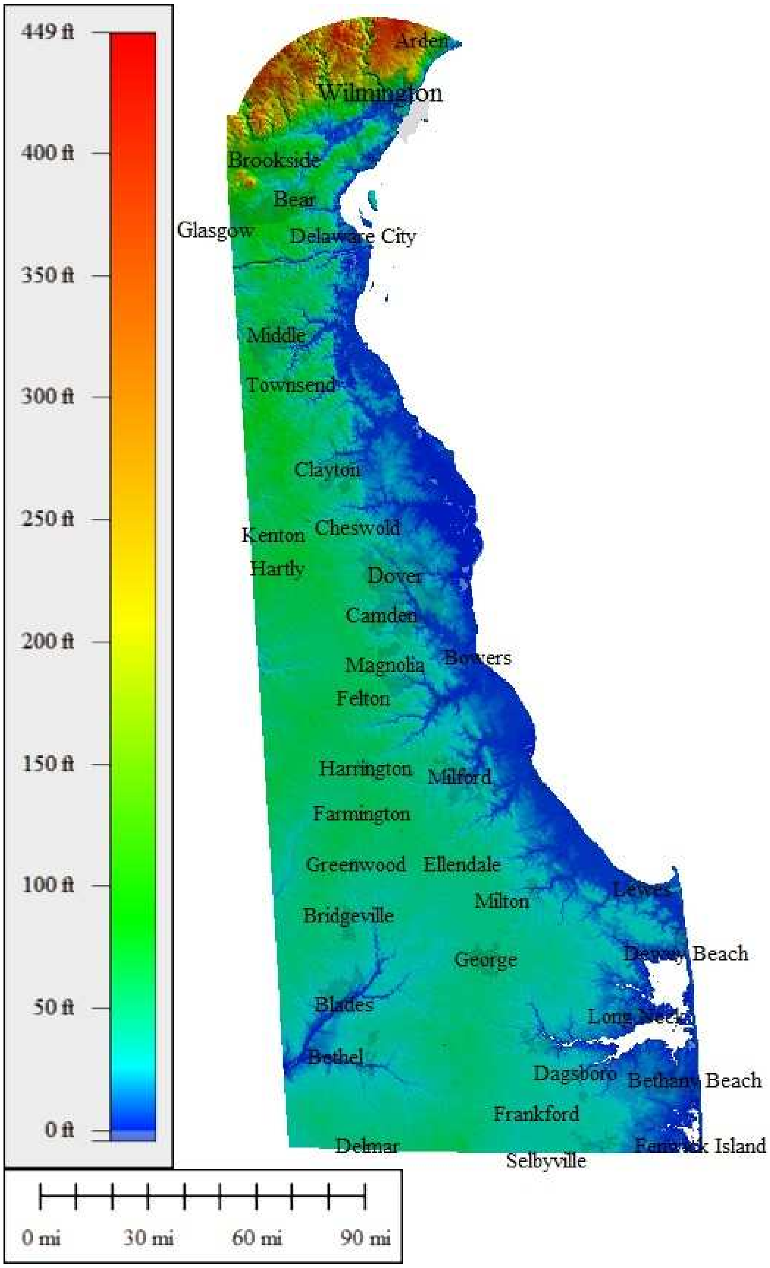
Dover, DE
Diane Shields
5/6/2012

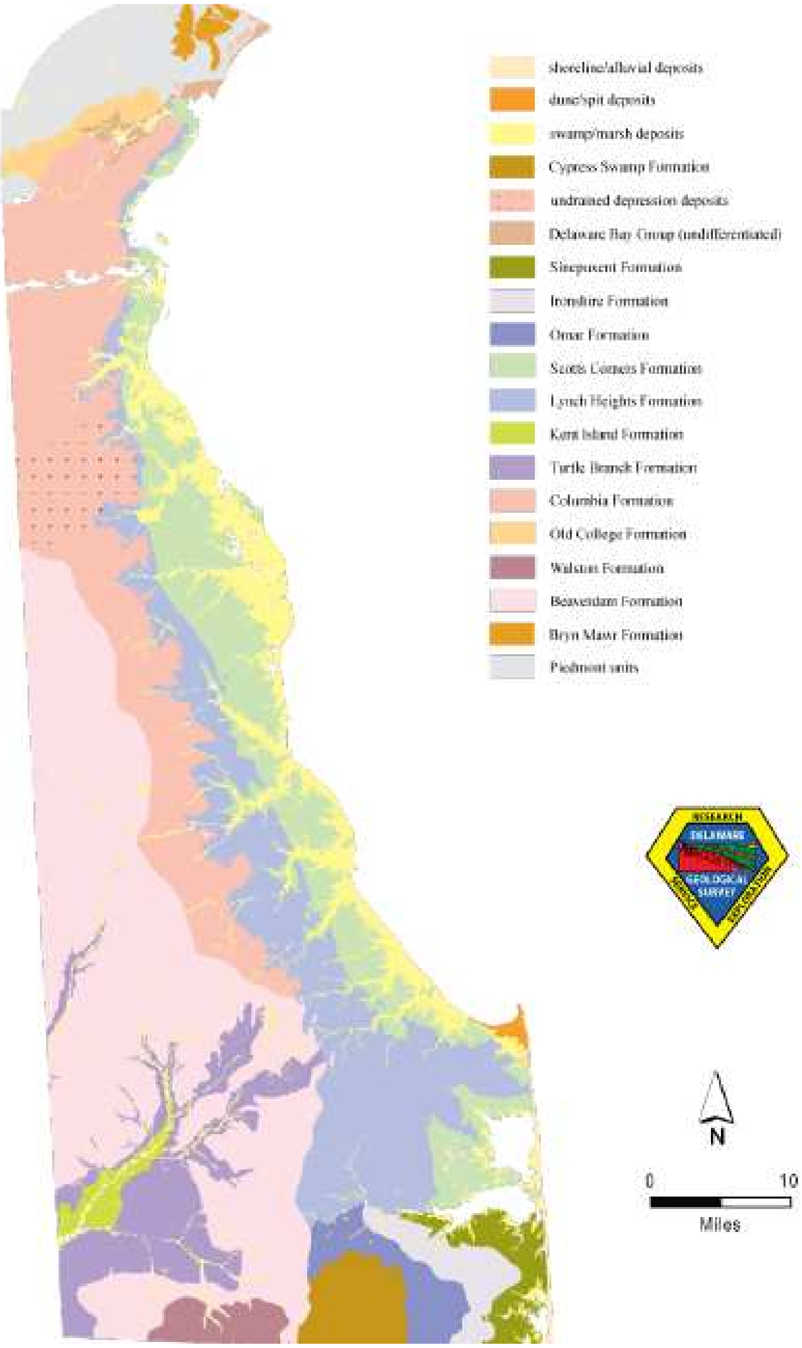
Map of Elevation in Delaware

Figure 10. Map depicting the elevation variation throughout Delaware. The highest point, Ebright Azimuth, which can be found at the Northern most edge of the state, stands at 448 feet above sea-level. Besides that point, the map depicts the low elevations seen throughout the rest of the state (Adapted from the United States Geological Survey/Topocreator).



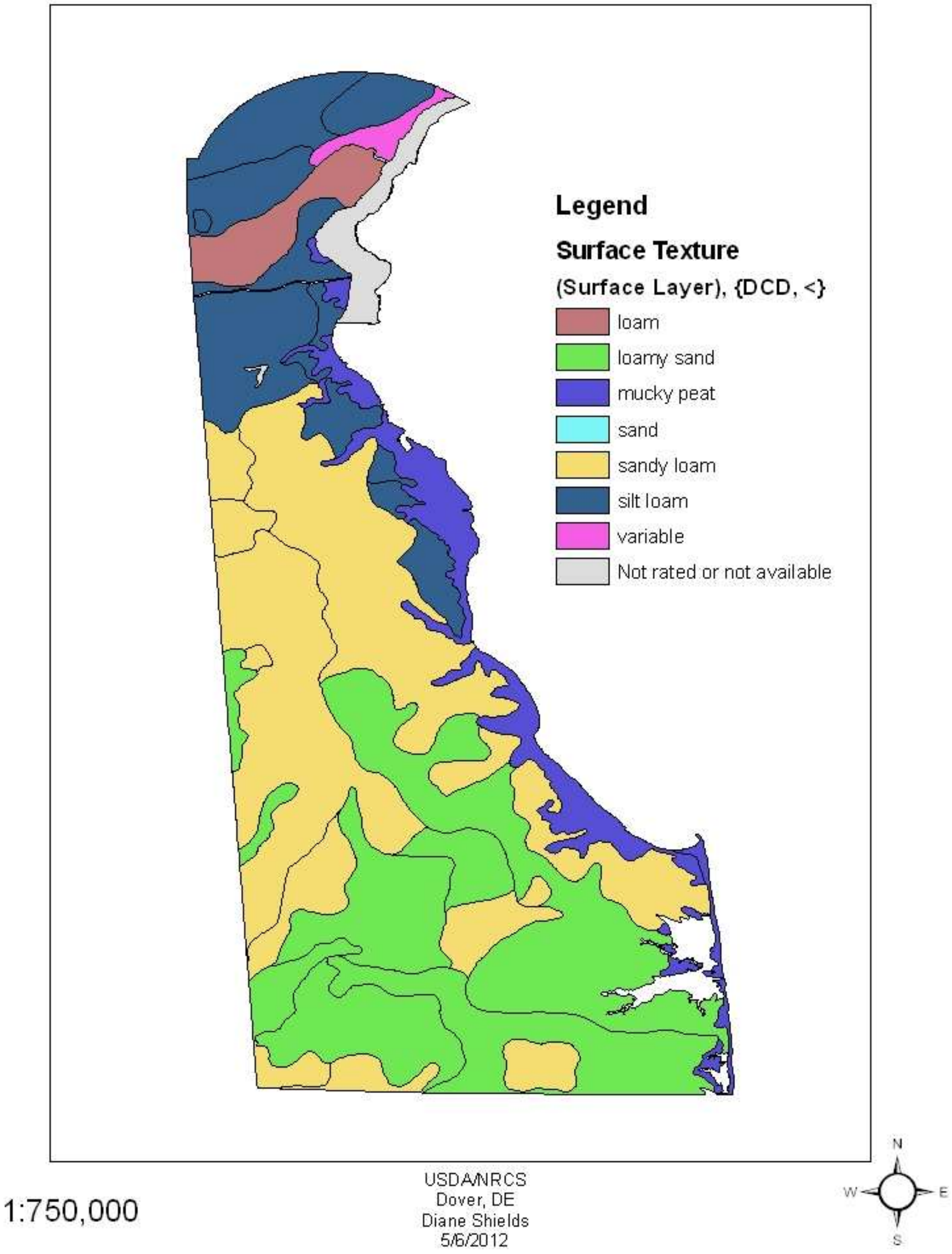
Deposits and Formations in Delaware

Figure 11. The various deposits and formations throughout Delaware are presented in the map. They may be of potential value in assessing preservation of buried remains (Adapted from the Delaware Geological Survey).



Soil Types in Delaware

Figure 12. This map depicts the various soil surface textures in Delaware, which may be of use in determining effects of soil on the rate of decay (Adapted from the United States Department of Agriculture/National Resources Conservation Service).



1:750,000

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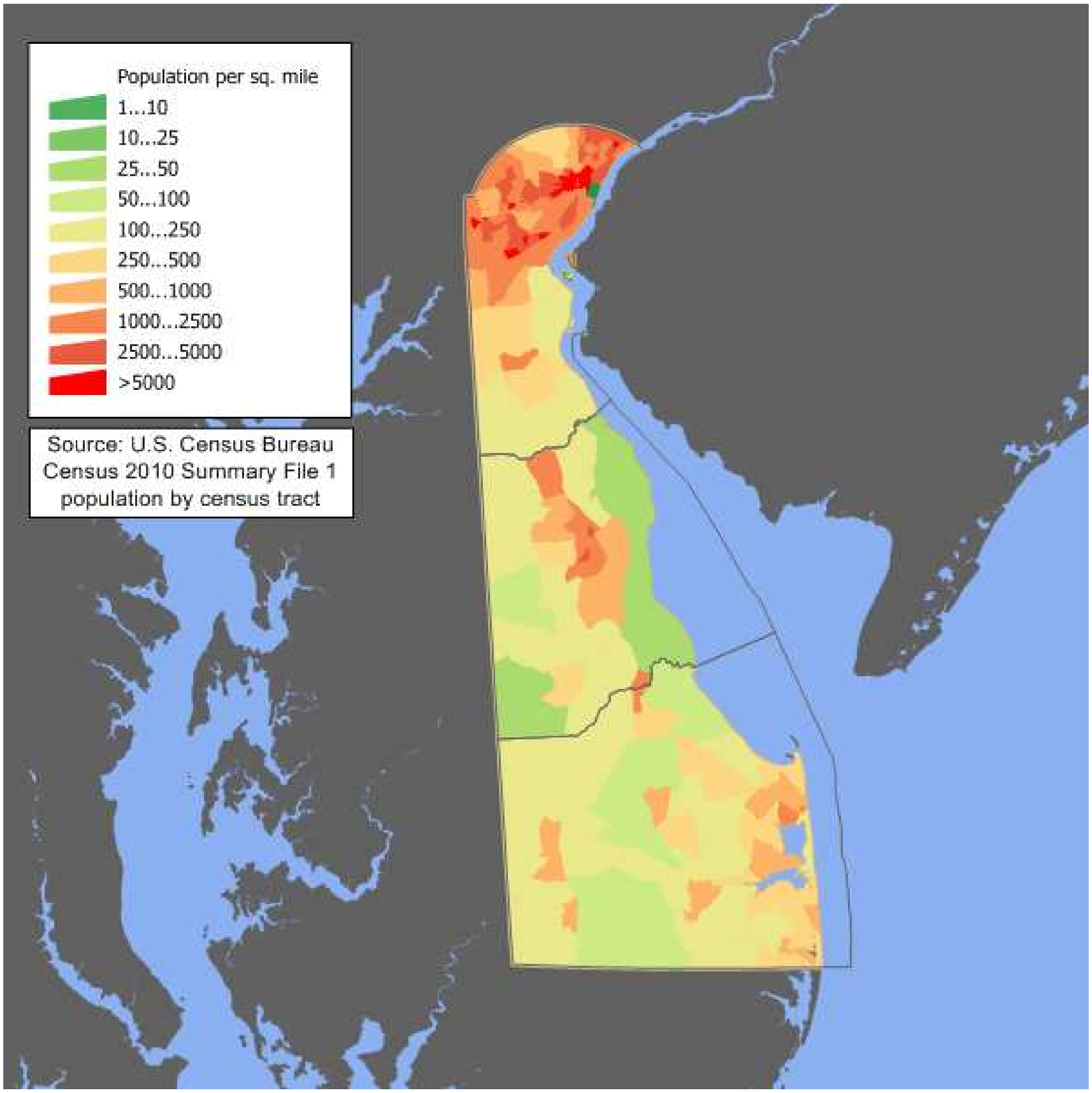
5/6/2012

Delaware Population per Square Mile

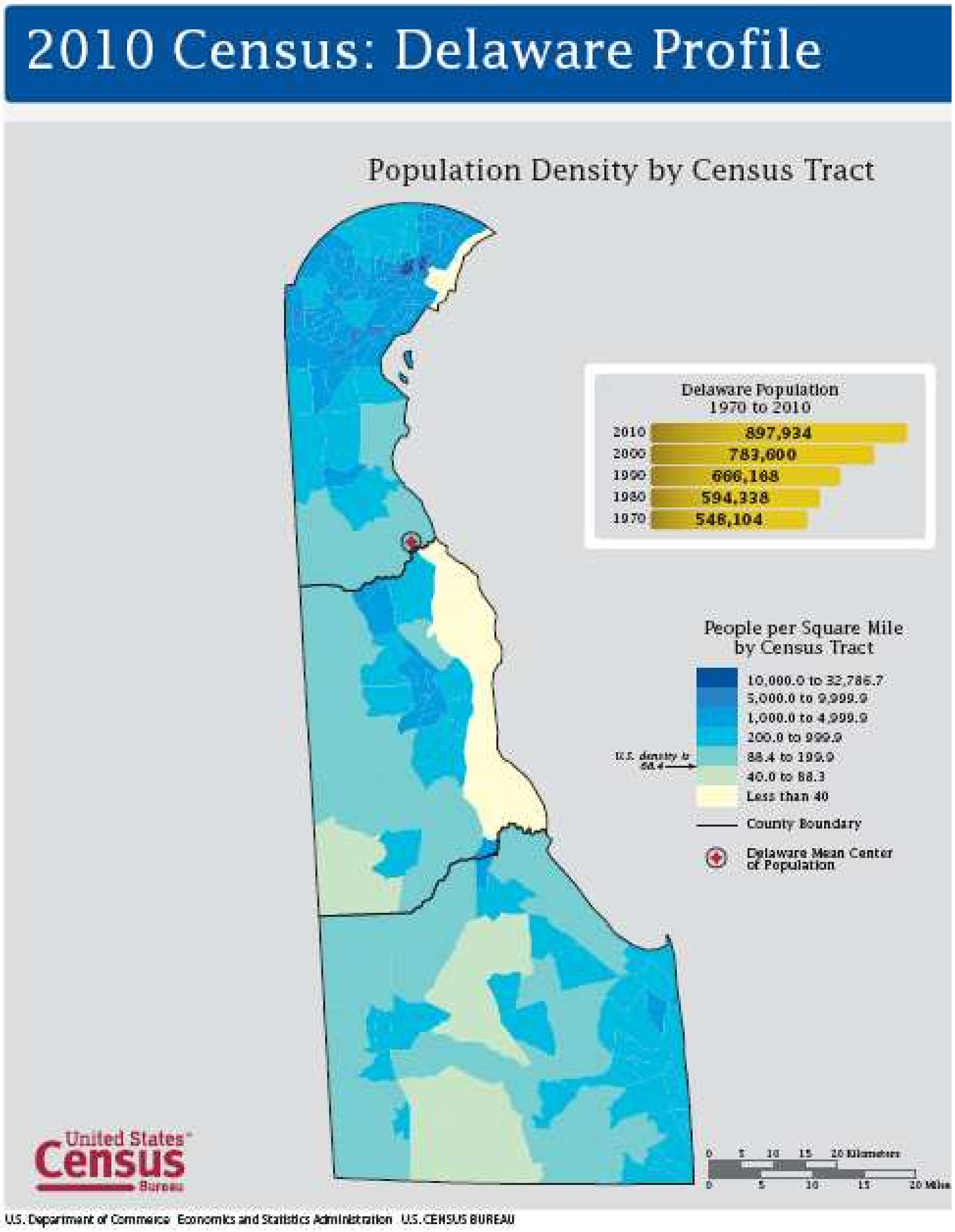
Figure 13. Delaware population density per square mile in 2010. The most densely populated areas of Delaware can be found in New Castle County, the most Northern County on the map (Adapted from the United States Census Bureau).



Source: U.S. Census Bureau
Census 2010 Summary File 1
population by census tract

Delaware Population Total Population Count

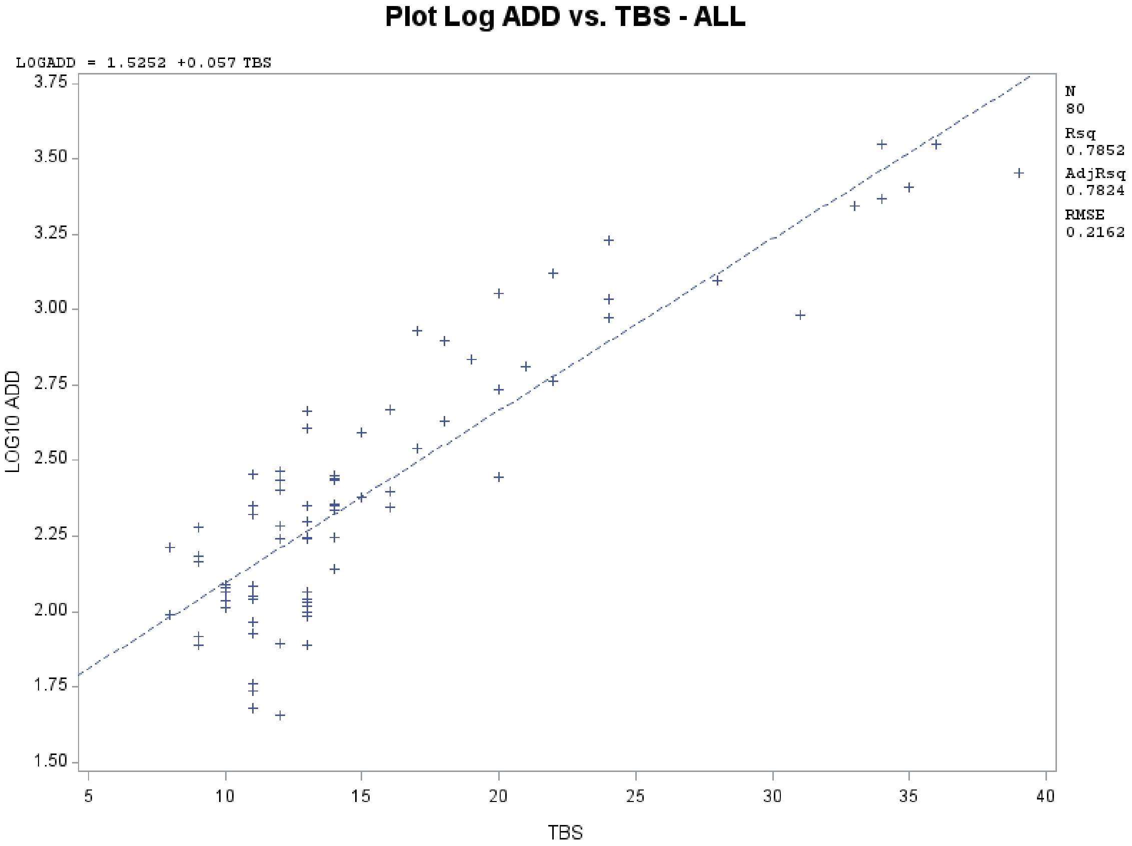
Figure 14. Delaware population density per square mile and total population numbers. An increase in population size has been seen every decade since 1970 (Adapted from the United States Census Bureau).



Overall Case Model

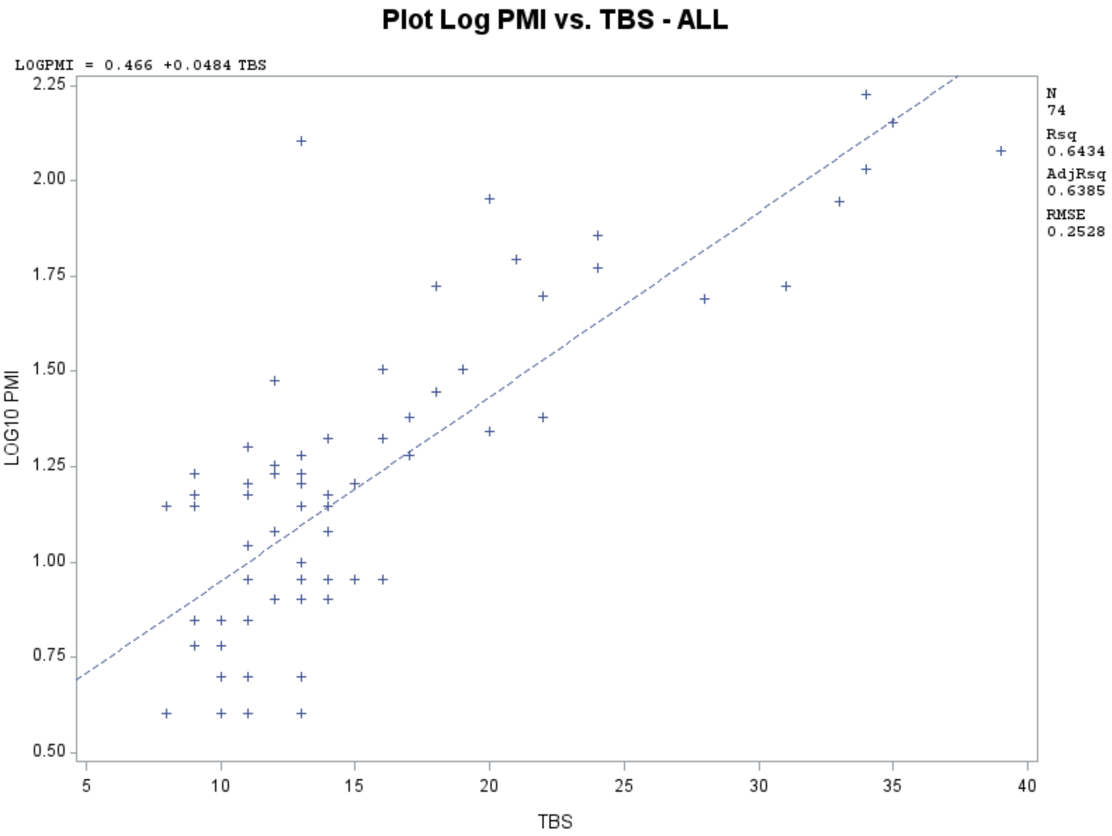
ADD Model: Plot LogADD versus TBS

Figure 15. The logarithm of Accumulated Degree Days plotted versus the Total Body Score. The calculated R^2 value and linear regression equation are displayed.



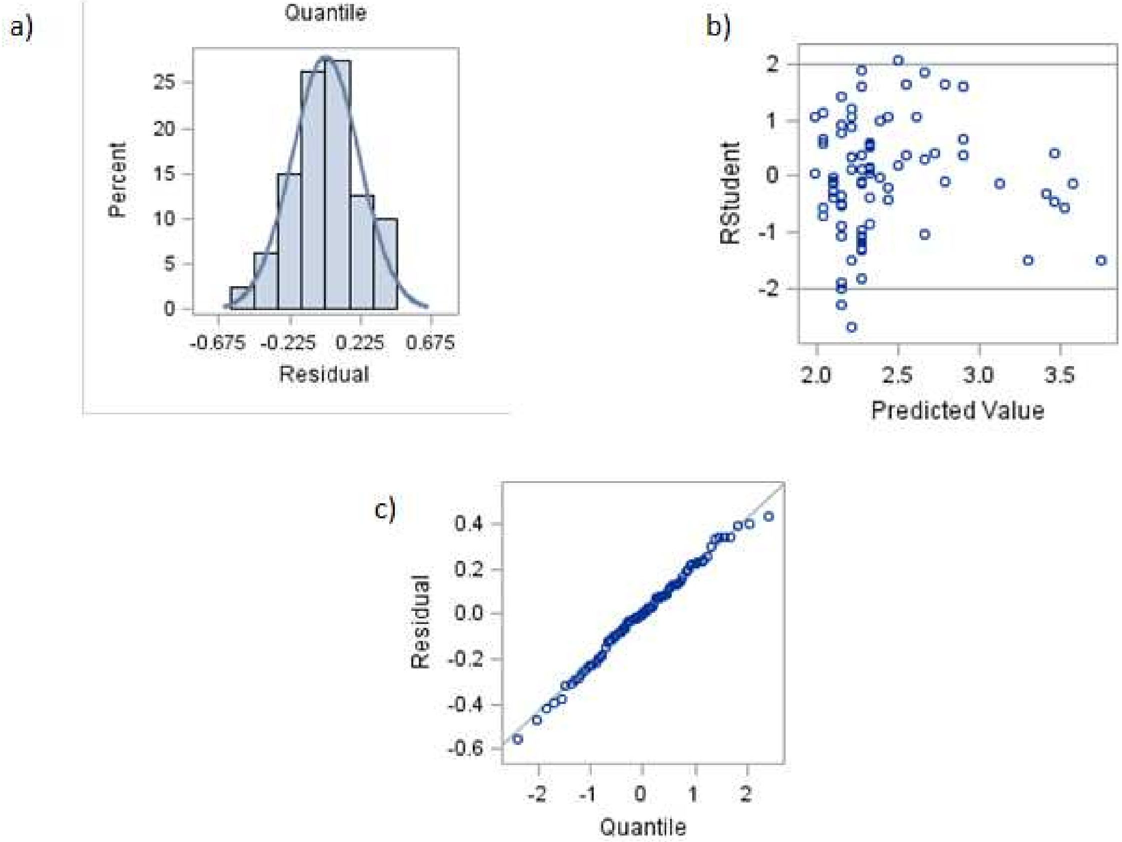
PMI Model: Plot LogPMI versus TBS

Figure 16. The logarithm of Post-Mortem Interval Days plotted versus the Total Body Score. The calculated R^2 value and linear regression equation are displayed.



ADD Model: Linear Regression Analysis Normality Assumption Tests

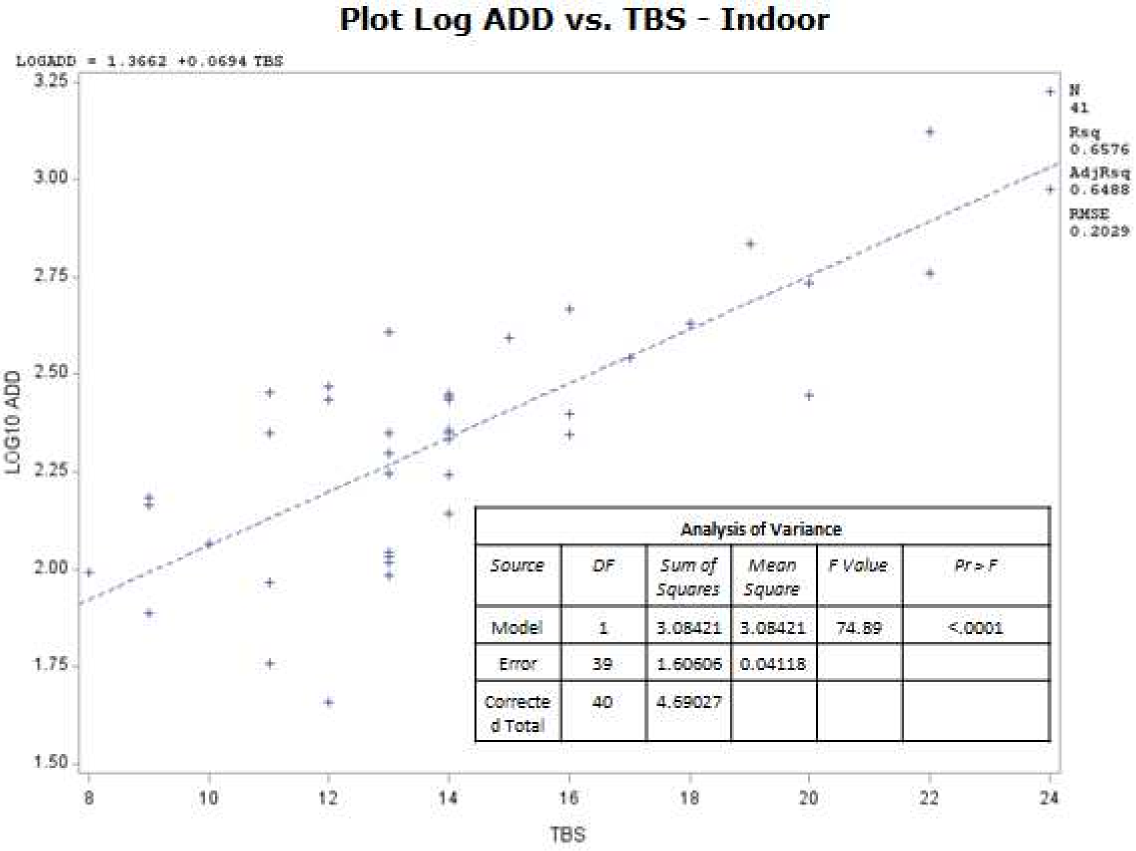
Figure 17. Depiction of the Normal Distribution of Residuals, Plot of Studentized Residuals versus Predicted Values, and the Probability Distribution of Residuals in the Accumulated Degree Day Model in order to satisfy the normality assumptions of linear regression analysis.



Stratified Analysis

<u>Indoor ADD Model: Plot LogADD versus TBS</u>

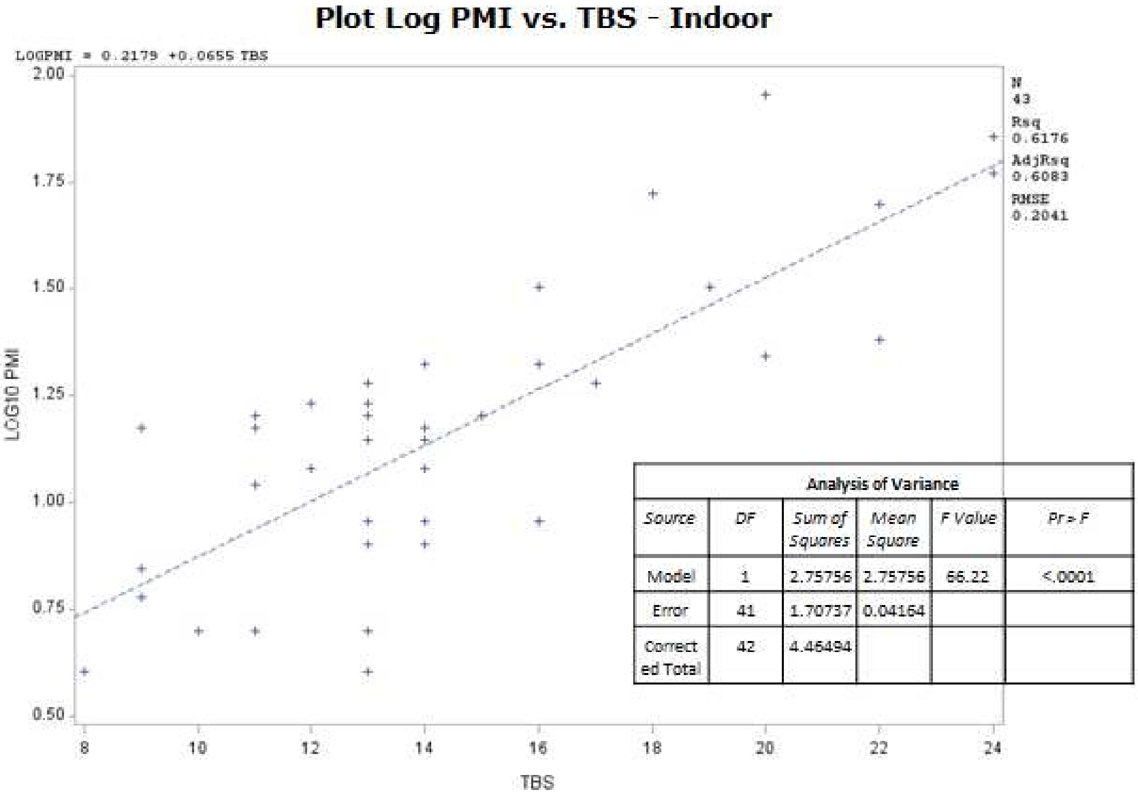
Figure 18. The logarithm of Accumulated Degree Days plotted versus the Total Body Score utilizing the indoor case subset. The calculated *R^2* value, linear regression equation, and ANOVA results are displayed.



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	3.08421	3.08421	74.89	<.0001
Error	39	1.60606	0.04118		
Corrected Total	40	4.69027			

Indoor PMI Model: Plot LogPMI versus TBS

Figure 19. The logarithm of Post-Mortem Interval days plotted versus the Total Body Score utilizing the indoor case subset. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.

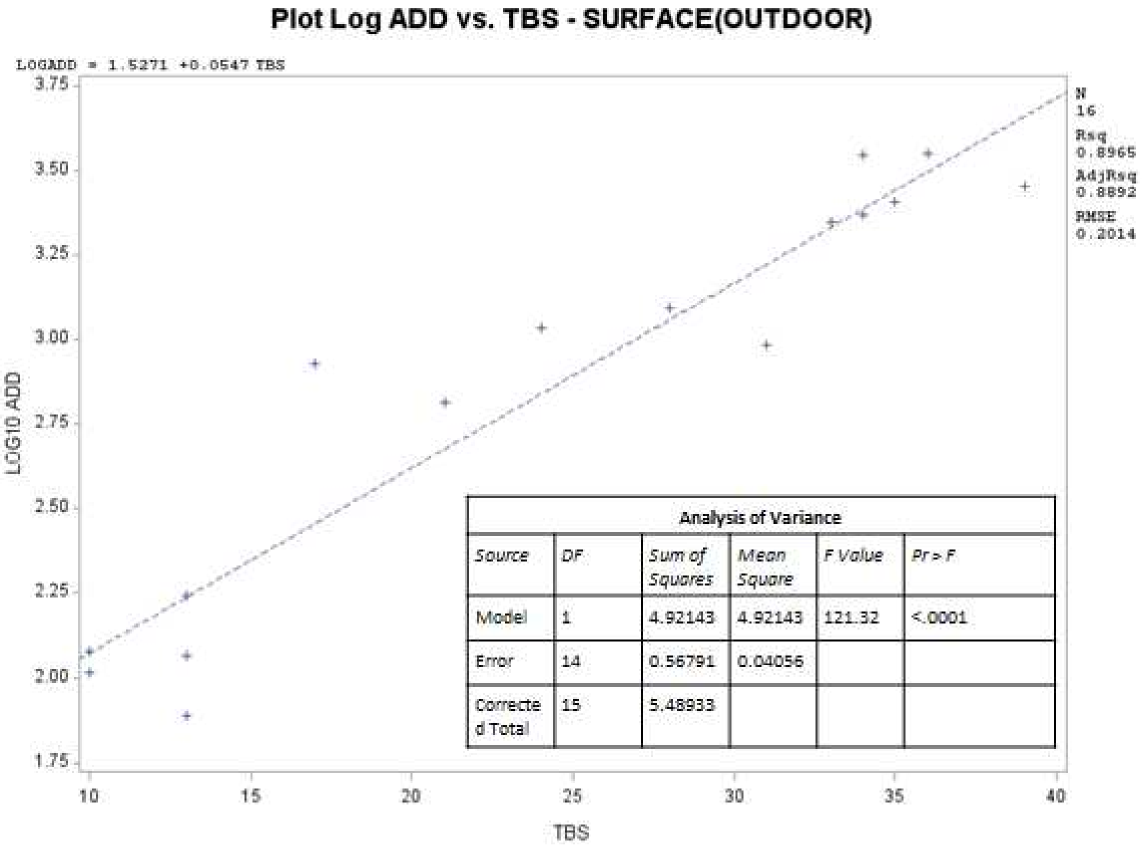


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	2.75756	2.75756	66.22	<.0001
Error	41	1.70737	0.04164		
Corrected Total	42	4.46494			

Non-Water Outdoor ADD Model: Plot LogADD versus TBS

Figure 20. The logarithm of Accumulated Degree Days plotted versus the Total Body Score utilizing the non-water outdoor case subset. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.

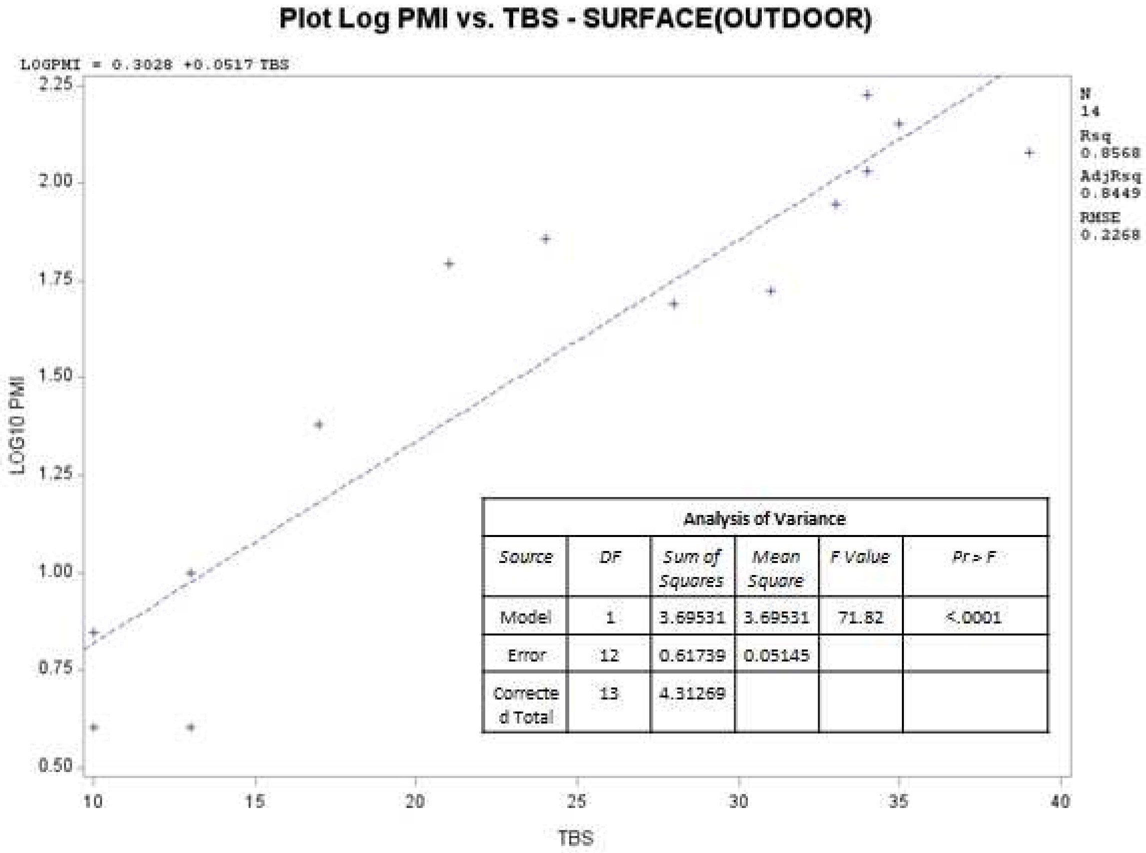


Analysis of Variance

Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	4.92143	4.92143	121.32	<.0001
Error	14	0.56791	0.04056		
Corrected Total	15	5.48933			

Non-Water Outdoor PMI Model: Plot LogPMI versus TBS

Figure 21. The logarithm of Post-Mortem Interval days plotted versus the Total Body Score utilizing the non-water outdoor case subset. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.

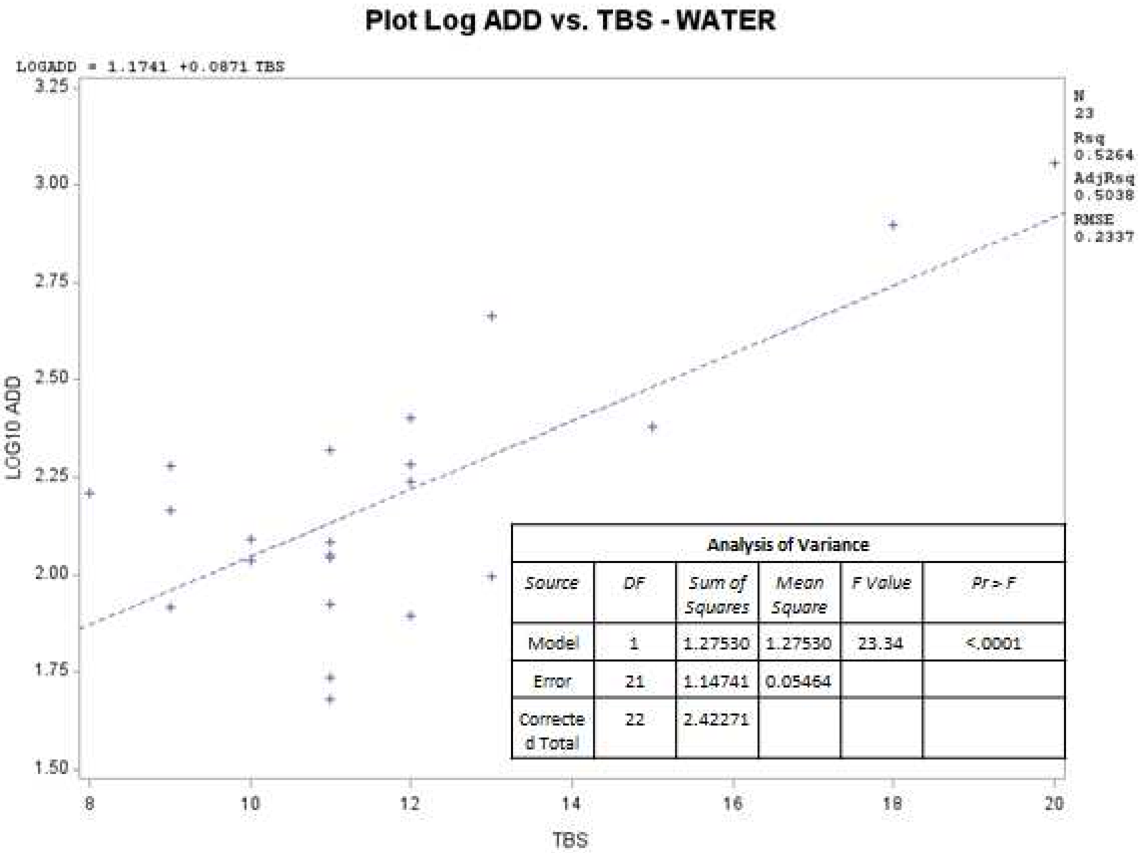


Analysis of Variance

Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	3.69531	3.69531	71.82	<.0001
Error	12	0.61739	0.05145		
Corrected Total	13	4.31269			

Aquatic ADD Model: Plot LogADD versus TBS

Figure 22. The logarithm of Accumulated Degree Days plotted versus the Total Body Score utilizing the aquatic case subset. The calculated *R*^{2} value, linear regression equation, and ANOVA results are displayed.

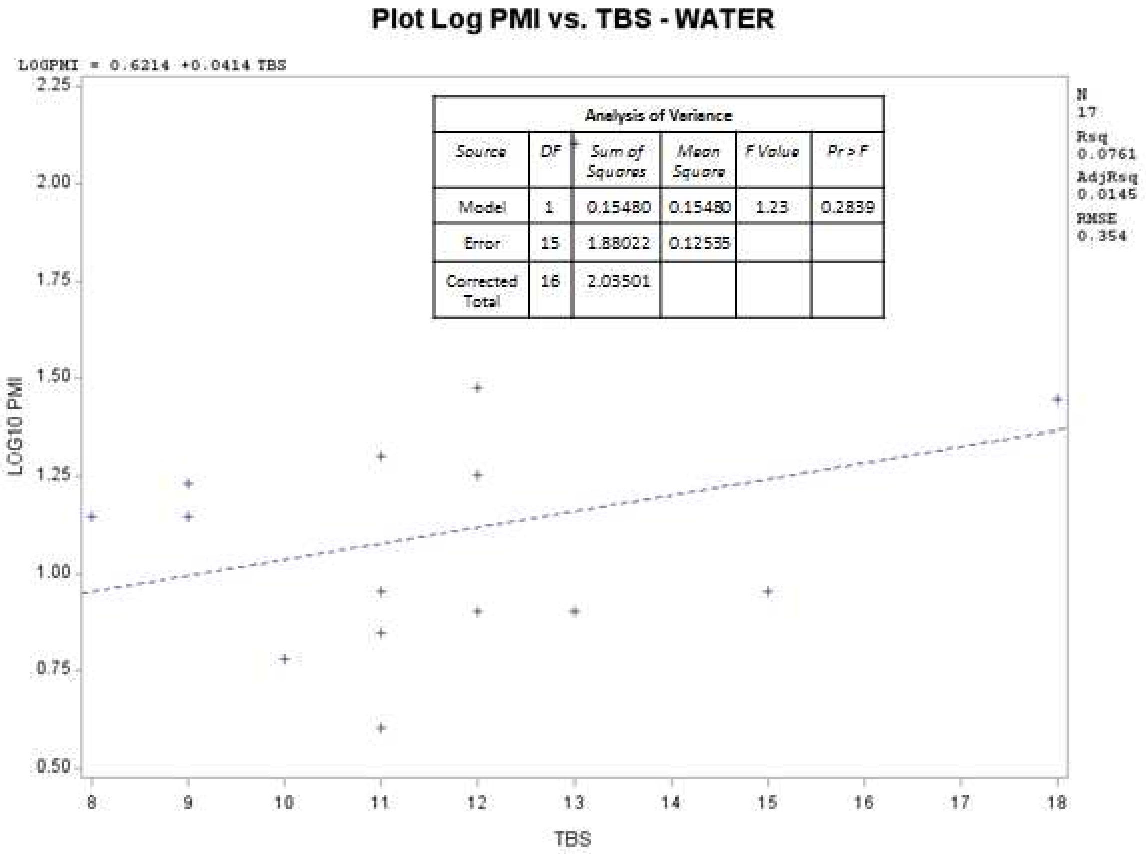


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.27530	1.27530	23.34	<.0001
Error	21	1.14741	0.05464		
Corrected Total	22	2.42271			

Aquatic PMI Model: Plot LogPMI versus TBS

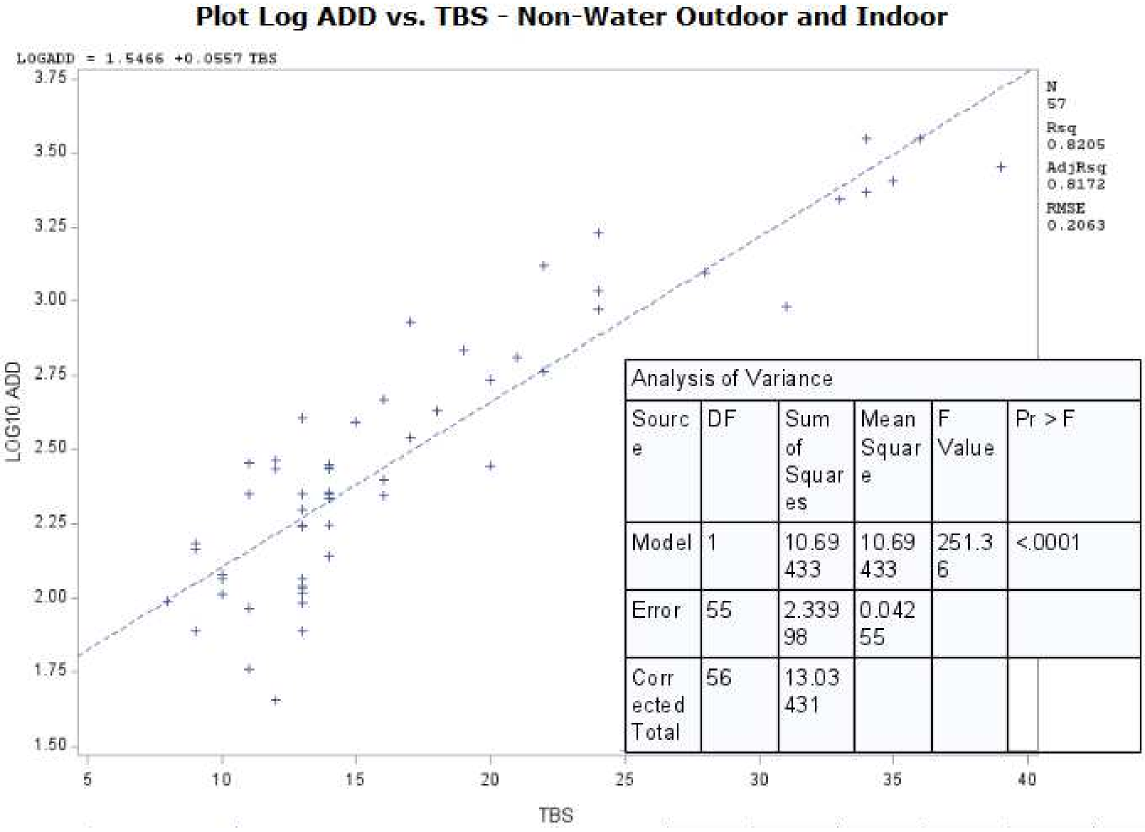
Figure 23. The logarithm of Post-Mortem Interval days plotted versus the Total Body Score utilizing the aquatic case subset. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	0.15480	0.15480	1.23	0.2839
Error	15	1.88022	0.12535		
Corrected Total	16	2.03501			

Non-Water Outdoor and Indoor ADD Model: Plot LogADD versus TBS

Figure 24. The logarithm of Accumulated Degree Days plotted versus the Total Body Score utilizing the non-water outdoor and indoor case subsets. The calculated *R^2* value, linear regression equation, and ANOVA results are displayed.



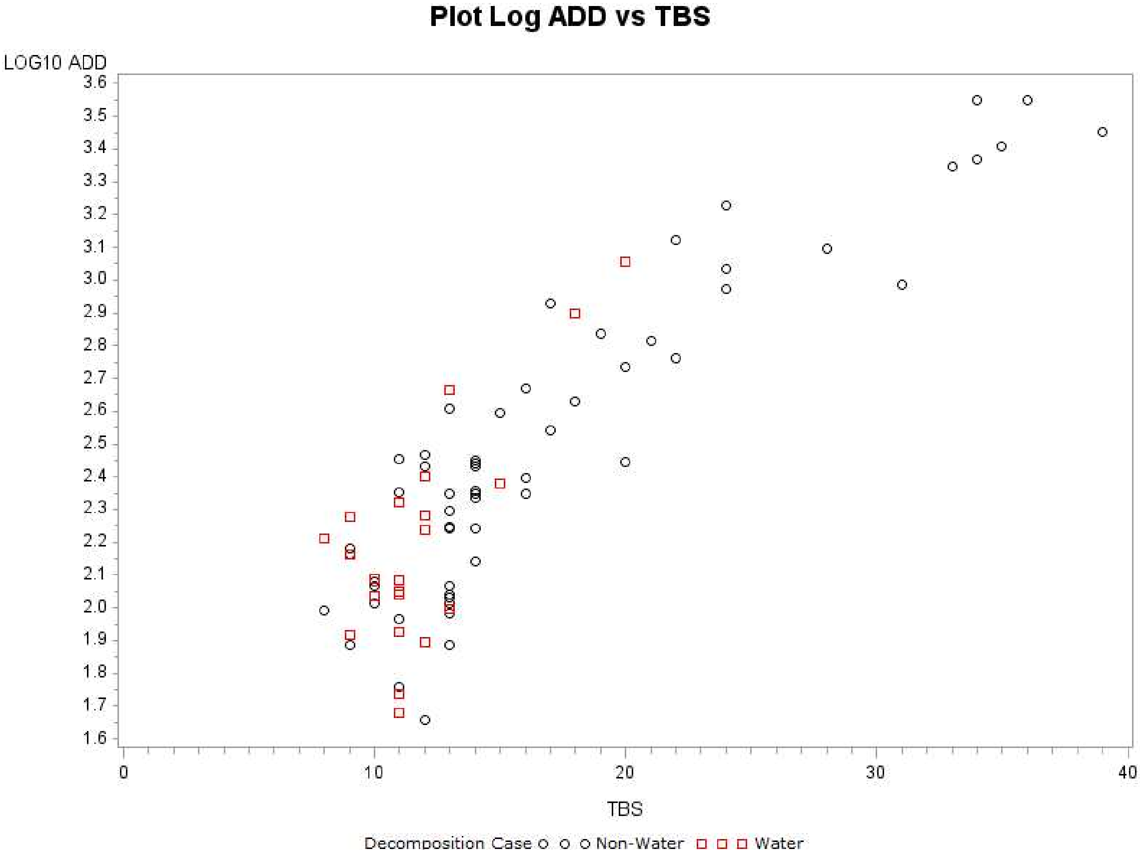
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	10.69433	10.69433	251.36	<.0001
Error	55	2.33998	0.04255		
Corrected Total	56	13.03431			

Continuous Plots

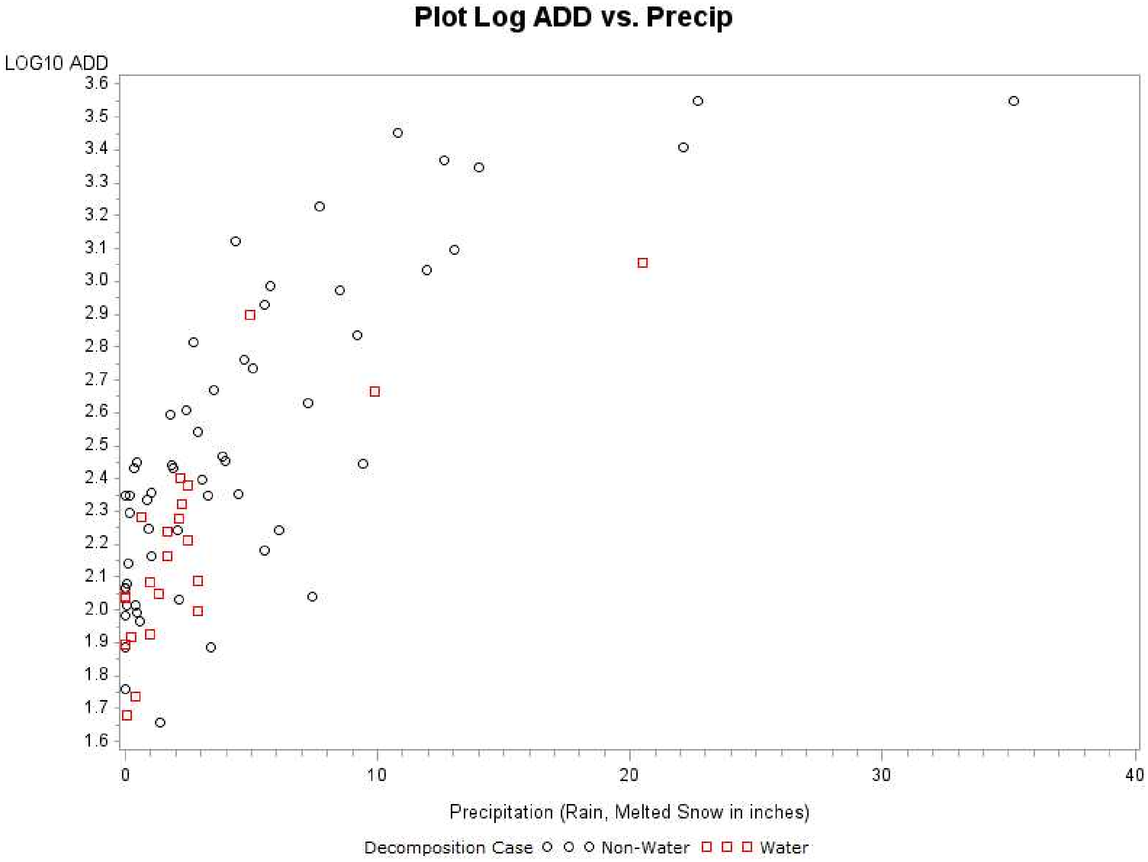
<u>Plot LogADD versus TBS</u>

Figure 25. The logarithm of Accumulated Degree Days plotted versus the Total Body Score utilizing all cases in the model. The same relationship is demonstrated across all depositional contexts.



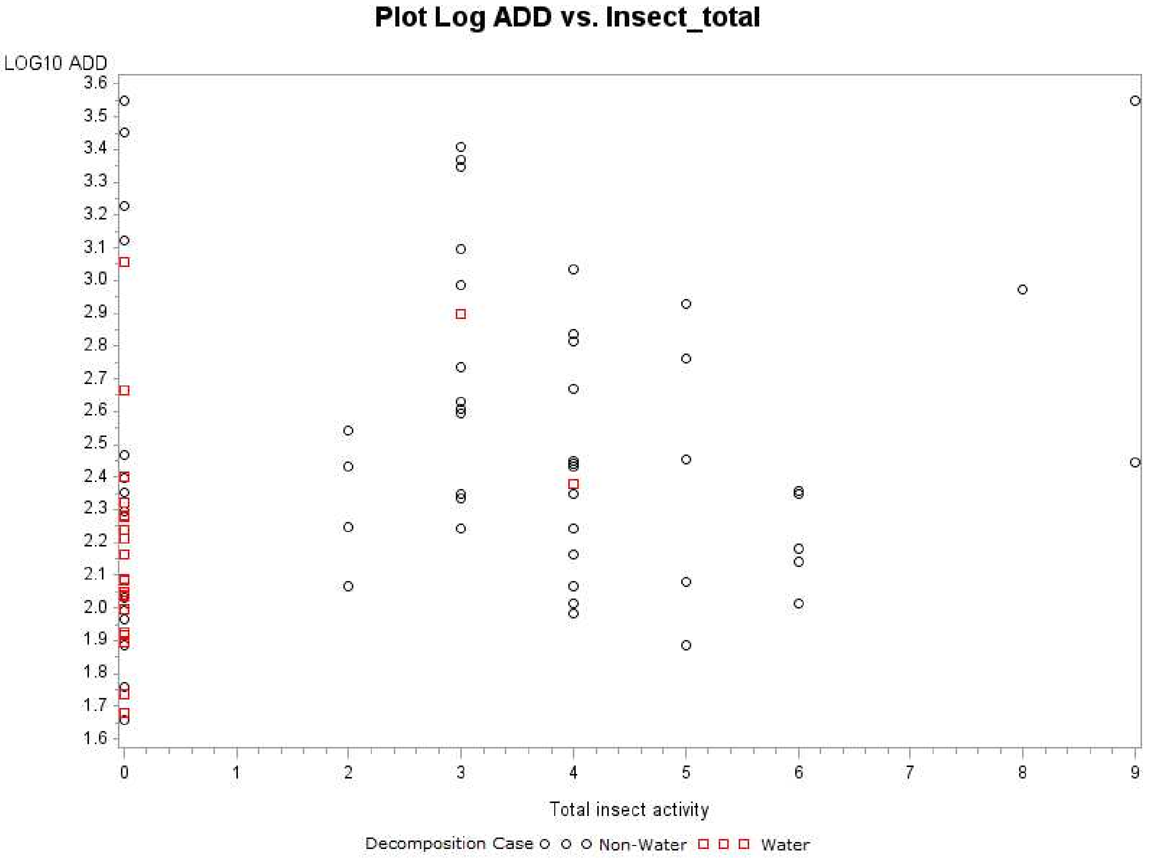
Plot LogADD versus Precipitation

Figure 26. The logarithm of Accumulated Degree Days plotted versus Precipitation utilizing all cases in the model. As precipitation levels increase, logADD appears to increase as well.



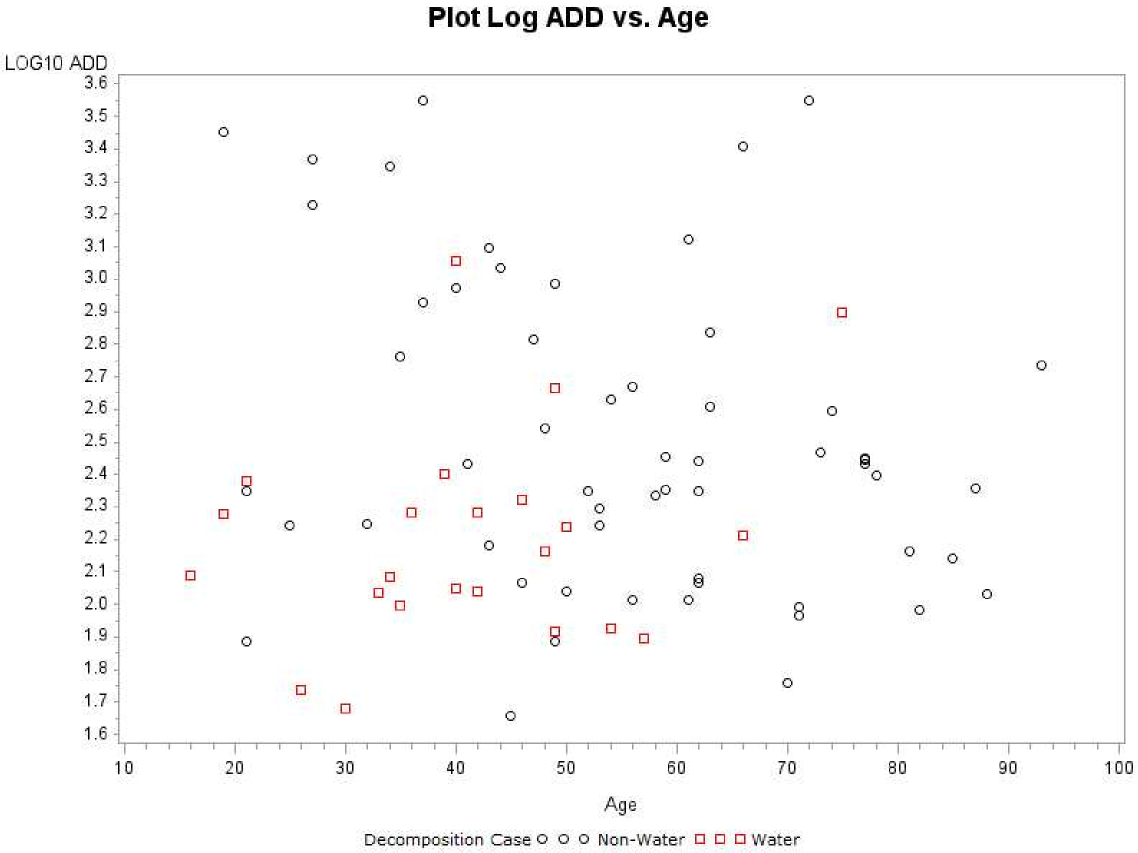
Plot LogADD versus Insect Activity

Figure 27. The logarithm of Accumulated Degree Days plotted versus Insect Activity utilizing all cases in the model. As insect presence begins to increase, logADD appears to increase as well. However, instead of leveling out, the relationship switches, potentially corresponding to the tail end of tissue consumption and migration.



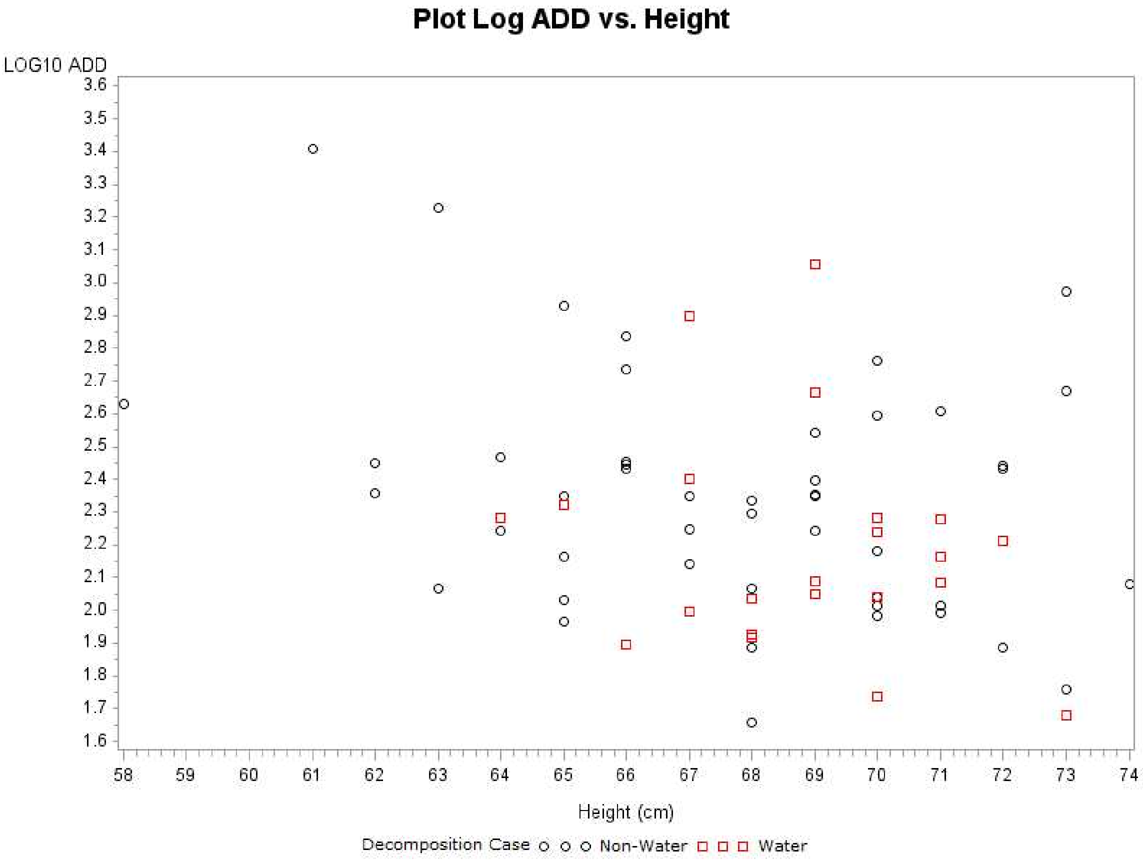
Plot LogADD versus Age

Figure 28. The logarithm of Accumulated Degree Days plotted versus Age utilizing all cases in the model. No relationship was observed.



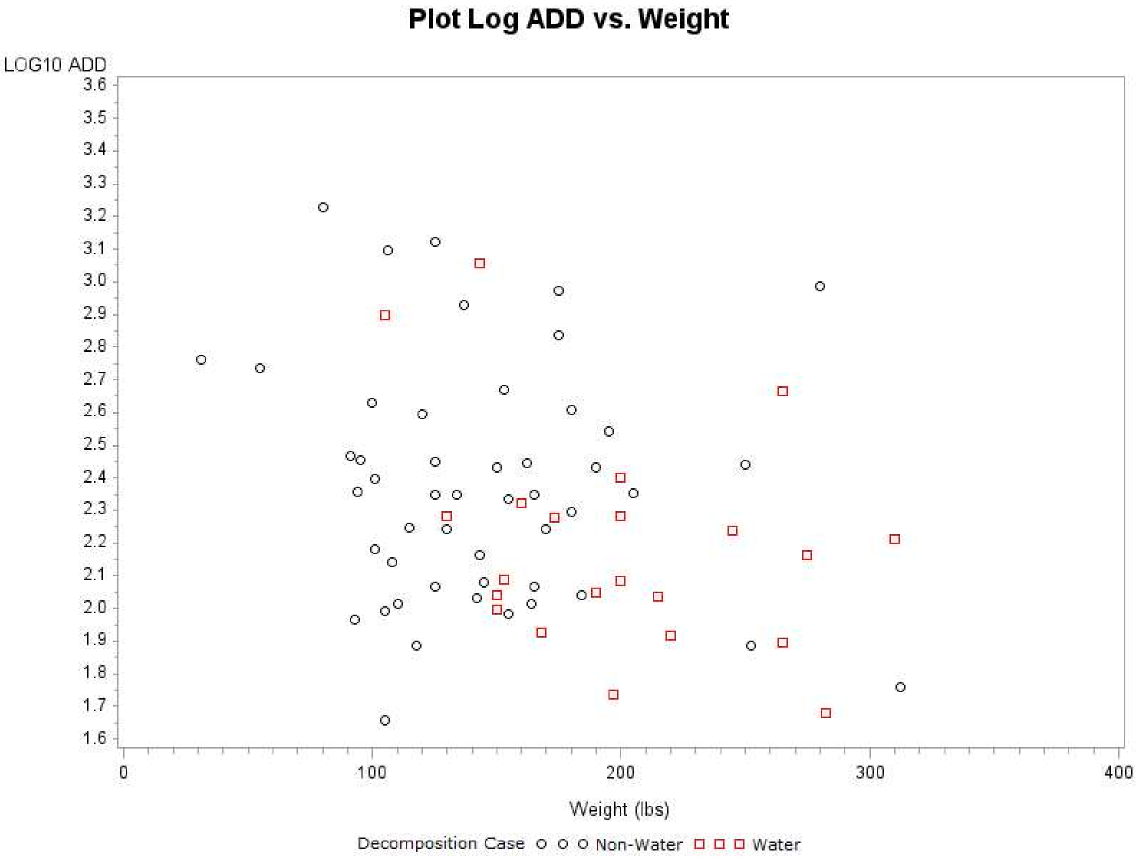
Plot LogADD versus Height

Figure 29. The logarithm of Accumulated Degree Days plotted versus Height utilizing all cases in the model. No relationship was observed.



Plot LogADD versus Weight

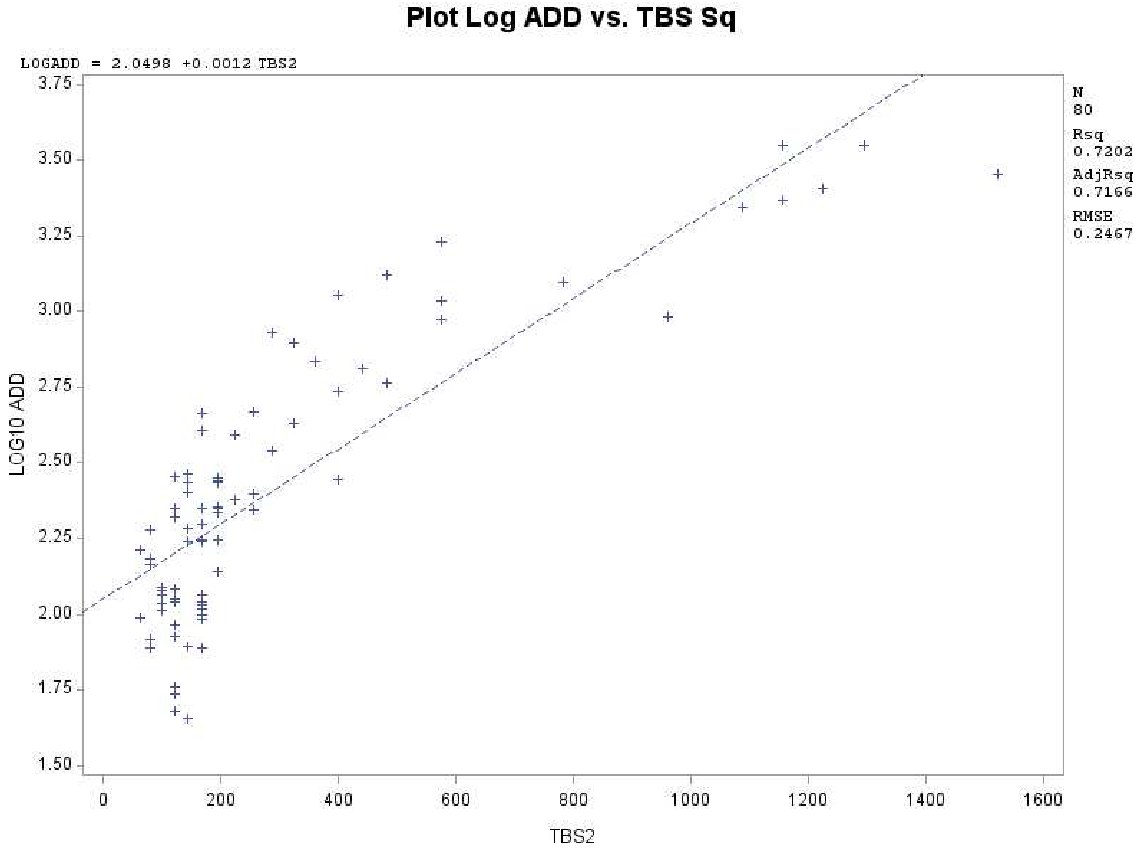
Figure 30. The logarithm of Accumulated Degree Days plotted versus Weight utilizing all cases in the model. No relationship was observed.



Model Comparison: Delaware River Valley versus Megyesi et al. (2005)

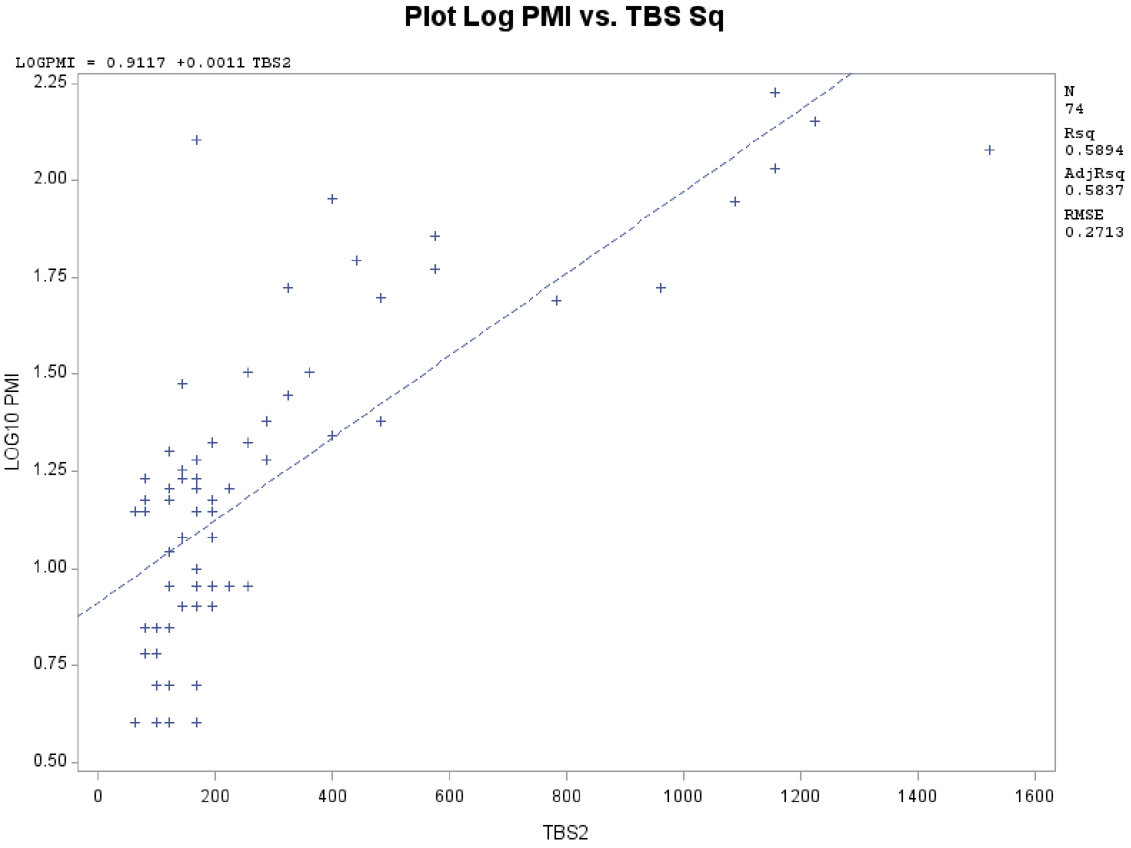
Megyesi et al. (2005) ADD Model with Delaware River Valley Data

Figure 31. The application of the Megyesi et al. (2005) Accumulated Degree Day Model, logADD versus TBS squared, to the entire ADD dataset extracted from the Delaware River Valley Region. The calculated R^2 value and linear regression equation are displayed.



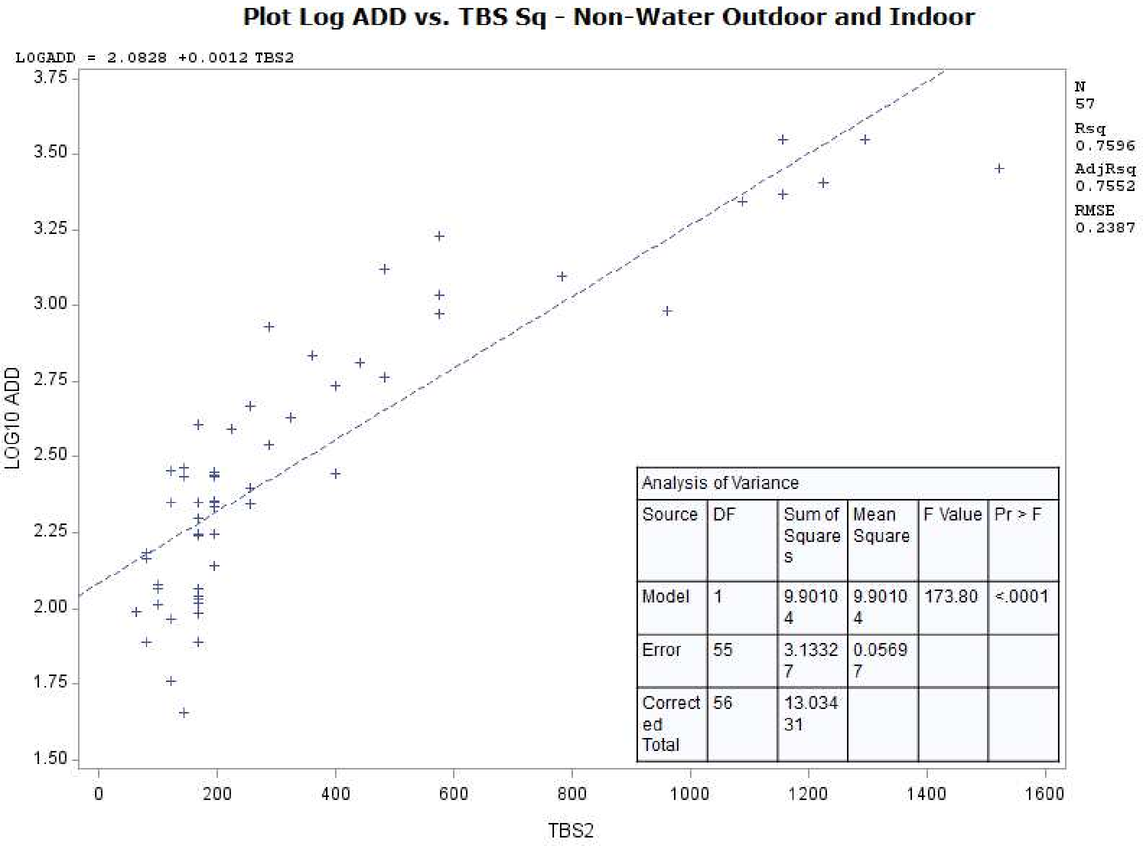
Megyesi et al. (2005) PMI Model with Delaware River Valley Data

Figure 32. The application of the Megyesi et al. (2005) Post-Mortem Interval Model, logPMI versus TBS squared, to the entire PMI dataset extracted from the Delaware River Valley Region. The calculated R^2 value and linear regression equation are displayed.



Megyesi et al. (2005) ADD Model with Delaware River Valley Outdoor and Indoor Data

Figure 33. The application of the Megyesi et al. (2005) Accumulated Degree Day Model, logADD versus TBS squared, to the combined outdoor and indoor ADD datasets extracted from the Delaware River Valley Region. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.

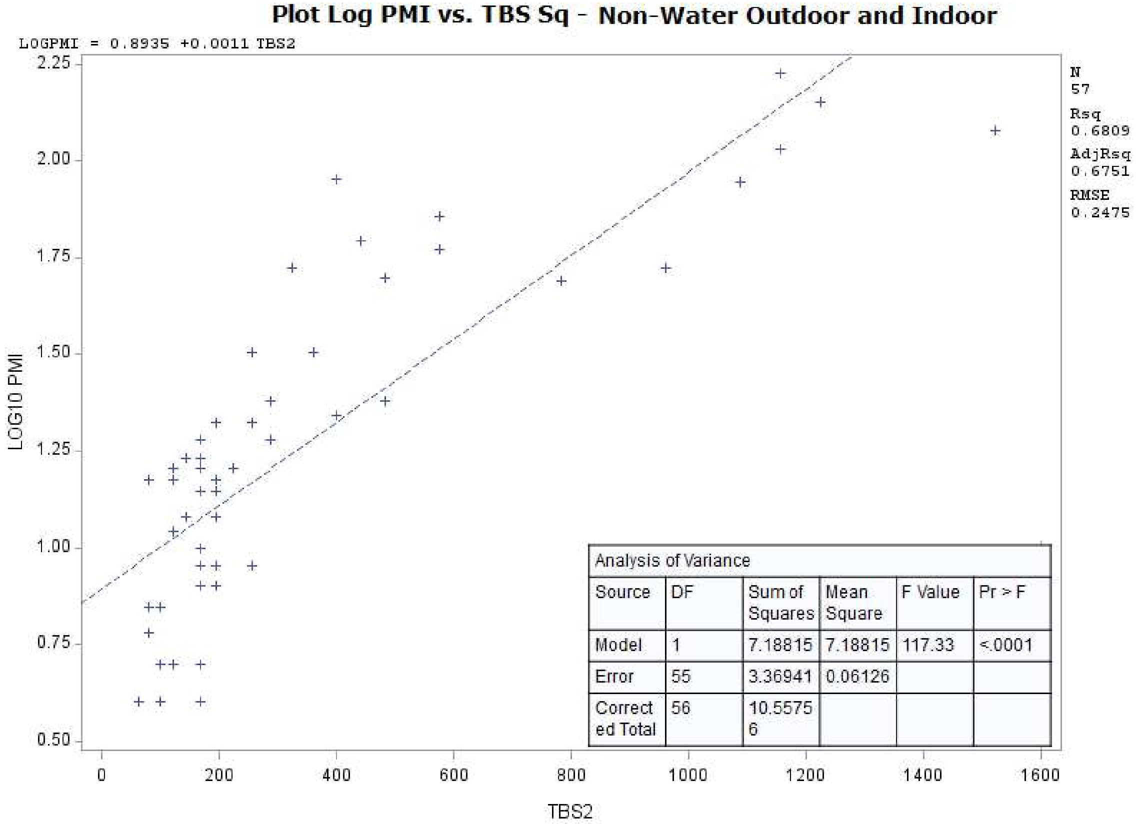


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	9.90104	9.90104	173.80	<.0001
Error	55	3.13327	0.05697		
Corrected Total	56	13.03431			

Megyesi et al. (2005) PMI Model with Delaware River Valley Outdoor and Indoor Data

Figure 34. The application of the Megyesi et al. (2005) Post-Mortem Interval Day Model, logPMI versus TBS squared, to the combined outdoor and indoor PMI datasets extracted from the Delaware River Valley Region. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.

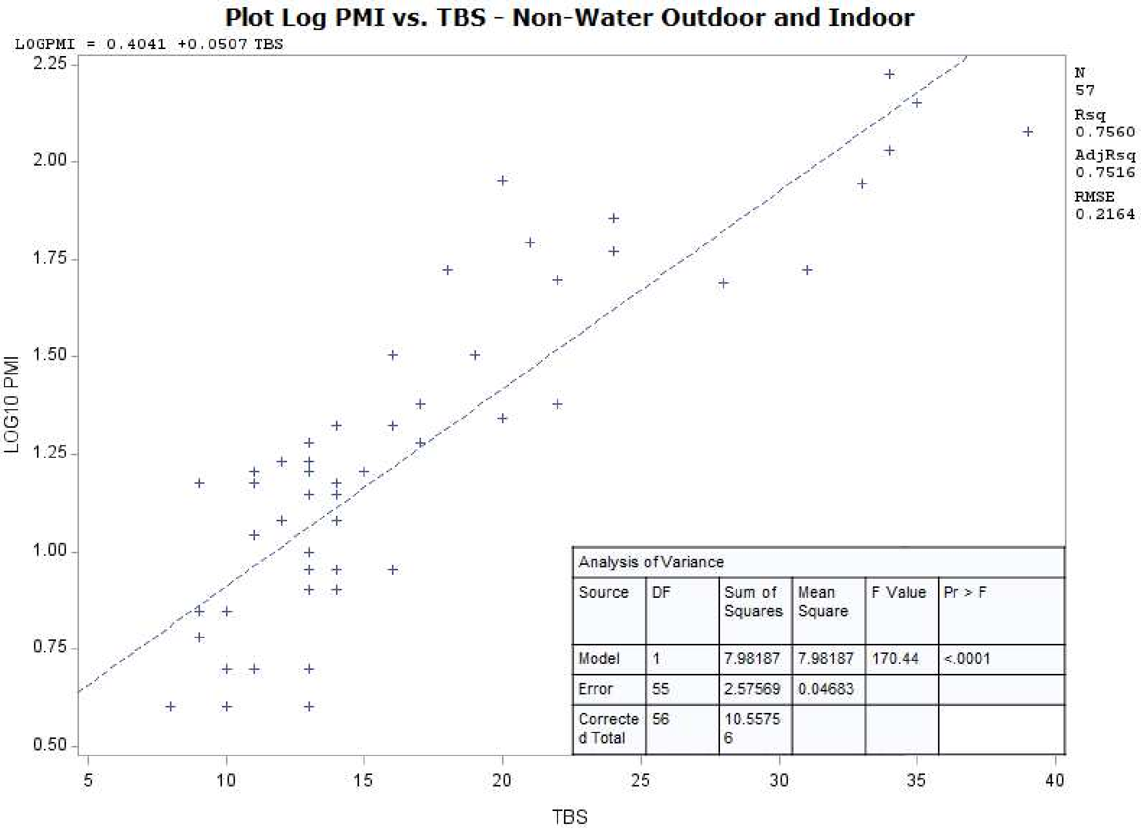


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	7.18815	7.18815	117.33	<.0001
Error	55	3.36941	0.06126		
Corrected Total	56	10.55756			

Non-Water Outdoor and Indoor PMI Model: Plot LogPMI versus TBS

Figure 35. The logarithm of Post-Mortem Interval days plotted versus the Total Body Score utilizing the non-water outdoor and indoor case subsets. The calculated R^2 value, linear regression equation, and ANOVA results are displayed.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	7.98187	7.98187	170.44	<.0001
Error	55	2.57569	0.04683		
Corrected Total	56	10.55756			

Appendix C: Technical Report

Introduction

In order to reach the final form of the model, several steps had to be taken to produce a model which included all relevant explanatory variables, eliminated unnecessary or troublesome factors, transformed the data when appropriate, and most accurately estimated time since death. This required a careful balance between attempting to explain as much of the variation in decomposition as possible, while including only those variables which make enough of an effect to warrant inclusion in the final models. Step by step explanations for the decisions made to produce the final models, starting with the original models calculated, are provided below. Additionally, the code utilized in SAS for both the accumulated degree day and post-mortem interval day analyses is attached. Complete transparency of all statistical steps taken is provided for a better understanding of the data and decompositional models produced.

As detailed throughout the chapters of this dissertation, one of the main questions to be addressed by this study pertained to whether accumulated degree days (ADD) or post-mortem interval (PMI) days explains the highest proportion of variation in decomposition. In order to do so, ADD and TBS, as well as PMI and TBS, were plotted against eachother. Upon analysis of the plots, as well as the normality, homogeneity of variance, and probability distributions of the residuals, it was observed that a logarithmic transformation would be needed to correct the non-linear distribution observed. Upon log transforming the data and achieving a linear relationship, it was demonstrated that ADD explains the highest proportion of variation in decomposition compared to PMI days. Total body score was also demonstrated to be a statistically significant variable across models and the most important aspect of accurately representing the decomposition process in a particular area. Given this discovery, a regression equation was developed incorporating the logarithm of ADD and the total body score. The model produced was deemed statistically significant.

Additionally, several stratified models were developed in order to assess if dividing each depositional context into subsets would explain a higher proportion of variation. It was also hoped that by doing so, the analysis would identify which subsets may be affected by confounding factors or conditions not yet considered. Based on shared decompositional traits, indoor and non-water outdoor cases were also combined into a single model and statistically analyzed. Although the overall model, including all ADD cases, was demonstrated to explain a high proportion of variation, the joint indoor and non-water outdoor formula also fared particularly well. In fact, given the similarities shared by non-water outdoor and indoor cases, this particular joint subset appears best-suited to modeling decomposition in those contexts, given the appearance of confounding factors and as-yet-unknown variables in aquatic environments. However, the use of each stratified model by itself, requires a larger sample size in order to be employed with any confidence.

Furthermore, statistically significant co-variates were searched for in both the overall and stratified models to determine if additional explanatory variables could be discovered. This also included assessing each variables impact on the rate of decay, as well as the impact of each depositional context on the rate of decay. Besides total body score, no additional co-variates were identified as producing statistically signficant effects across each model, thus not warranting inclusion. In regards to the rate of decomposition, when assessing the ADD required to produce scores from the entire total body score range, bodies deposited in non-water outdoor contexts appear to decompose at a faster rate than those in indoor contexts.

Lastly, the models developed for the Delaware River Valley region were compared to those formulated in the Megyesi et al. (2005) study. In total, the model developed for this particular region was deemed to be more accurate at estimating time since death than the Megyesi et al. (2005) model, validating the development of region-specific standards and providing a time since death estimation formula which is best-suited to this area.

Logarithmic Transformation to Achieve Normality

Before removing outliers and extracting cases from the dataset, an assessment was made regarding the normality and linearity of the relationship between accumulated degree days versus total body score, as well as post-mortem interval days versus total body score, thus demonstrating if a transformation of the data was necessary. In order to do so, the plot of both groups was analyzed, along with the normality, homogeneity of variance, and probability distributions of the residuals. Upon examination of these plots, it was observed that the data did not demonstrate a linear relationship or normal distribution in either the ADD or PMI models (see Figures 1, 2, 3, and 4). The analysis of variance indicated that both models are statistically significant, while the parameter estimates for both models deemed the intercept and total body score to be statistically significant (see Tables 1 and 2).

Figure 1. Accumulated Degree Days plotted versus the Total Body Score. The calculated R^2 value and linear regression equation are displayed.

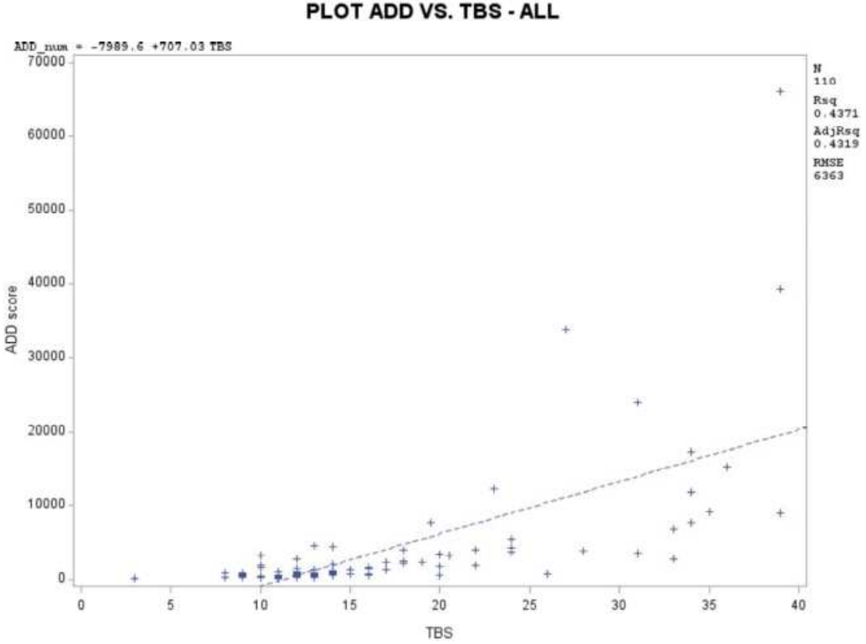


Figure 2. Depiction of the Non-Normal Distribution of Residuals, Plot of Studentized Residuals versus Predicted Values, and the Probability Distribution of Residuals in the Accumulated Degree Day Model in order to satisfy the normality assumptions of linear regression analysis.

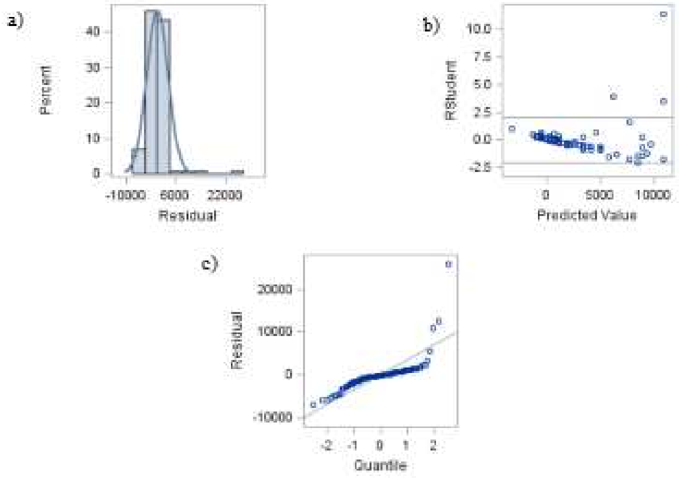
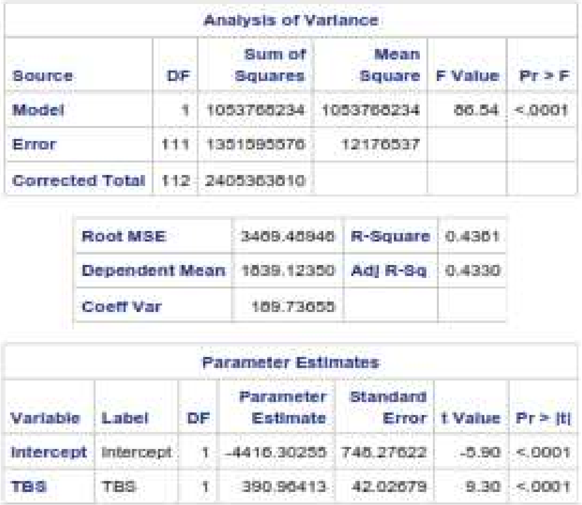


Table 1. Analysis of Variance and Parameter Estimates for the Accumulated Degree Day Model. The *p*-values for statistical significance are displayed.



Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1053768234	1053768234	86.54	<.0001
Error	111	1351595576	12176537		
Corrected Total	112	2405363810			

Root MSE	3489.45946	R-Square	0.4381
Dependent Mean	1839.12350	Adj R-Sq	0.4330
Coeff Var	189.73655		

Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-4416.30255	746.27622	-5.90	<.0001
TBS	TBS	1	390.96413	42.02679	9.30	<.0001

Figure 3. Post-Mortem Interval Days plotted versus the Total Body Score. The calculated R^2 value and linear regression equation are displayed.

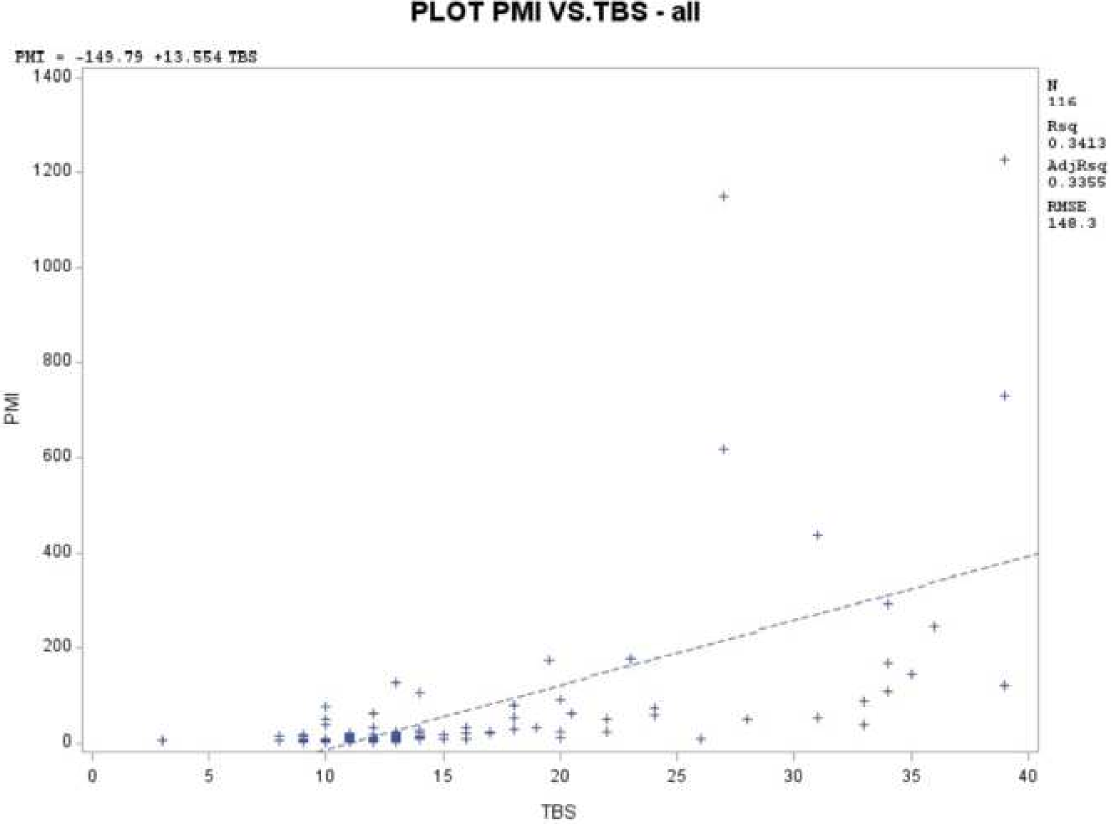


Figure 4. Depiction of the Non-Normal Distribution of Residuals, Plot of Studentized Residuals versus Predicted Values, and the Probability Distribution of Residuals in the Post-Mortem Interval Day Model in order to satisfy the normality assumptions of linear regression analysis.

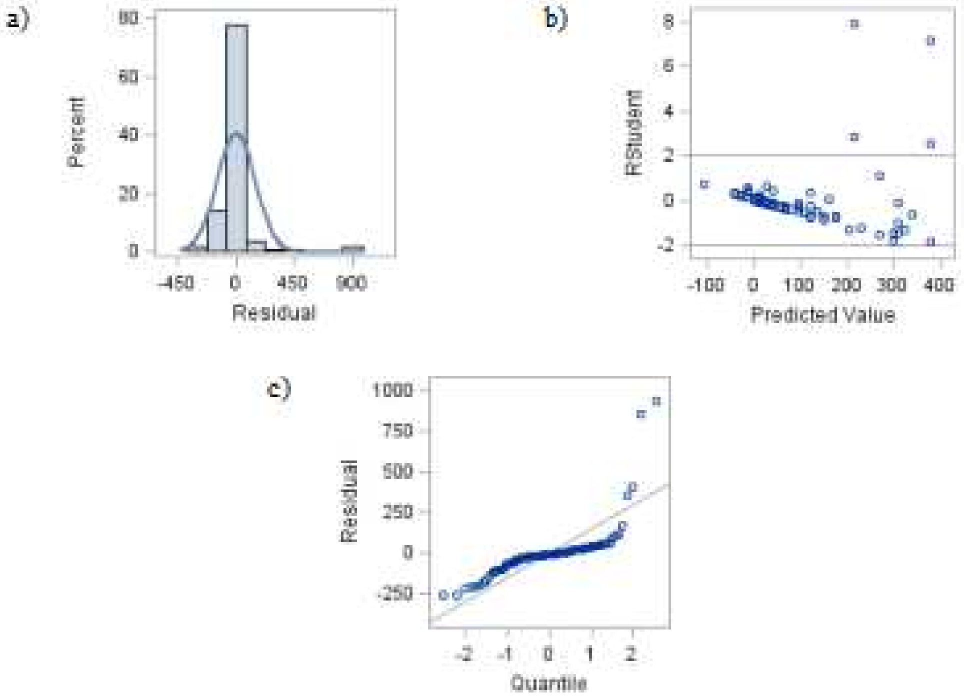
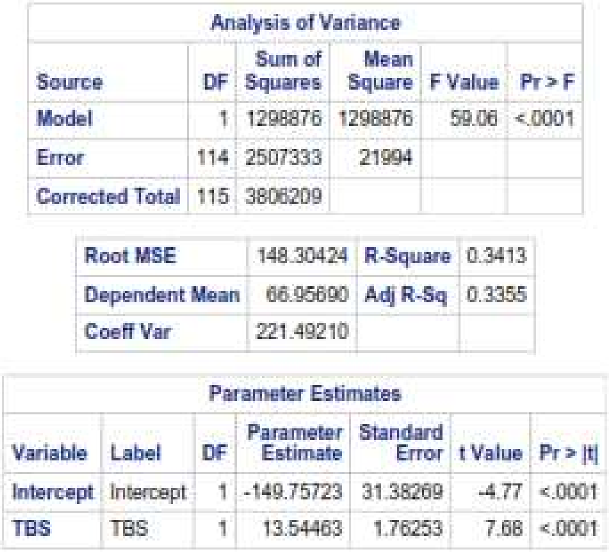


Table 2. Analysis of Variance and Parameter Estimates for the Post-Mortem Interval Day Model. The *p*-values for statistical significance are displayed.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1298876	1298876	59.06	<.0001
Error	114	2507333	21994		
Corrected Total	115	3806209			

Root MSE	148.30424	R-Square	0.3413
Dependent Mean	66.95690	Adj R-Sq	0.3355
Coeff Var	221.49210		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-149.75723	31.38269	-4.77	<.0001
TBS	TBS	1	13.54463	1.76253	7.68	<.0001

Before discussing the transformation of the data, it should be noted that a typical linear regression analysis seeks to develop an equation which attempts to minimize the distance between a “line of best fit” and observed values. A standard least-squares linear regression attempts to reduce the sum of the square of residuals, measured as the difference between observed and fitted values. However, given the lack of a linear relationship in either the ADD or PMI plots, a standard least-squares linear regression was not appropriate, instead requiring the transformation of variables. Thus, in order to straighten the curve, and allow for a more direct least-squares linear regression, it was determined that log-transforming both ADD and PMI, while leaving TBS untransformed, produces the most effective linear regression and normal distribution (see Figures 5, 6, 7, and 8). Upon doing so, the analysis of variance indicated that both models are statistically significant, while the parameter estimates for both models deemed the intercept and total body score to be statistically significant (see Tables 3 and 4).

Figure 5. The logarithm of Accumulated Degree Days plotted versus the Total Body Score. The calculated R^2 value and linear regression equation are displayed.

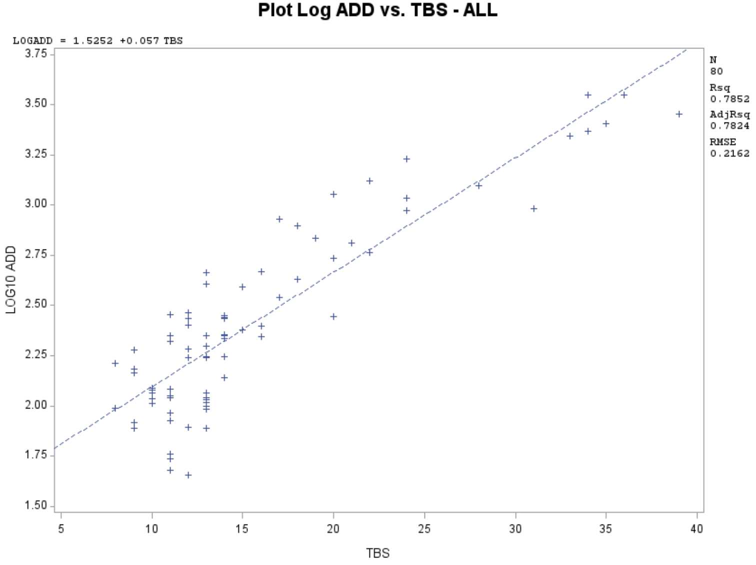


Figure 6. Depiction of the Normal Distribution of Residuals, Plot of Studentized Residuals versus Predicted Values, and the Probability Distribution of Residuals in the Accumulated Degree Day Model in order to satisfy the normality assumptions of linear regression analysis.

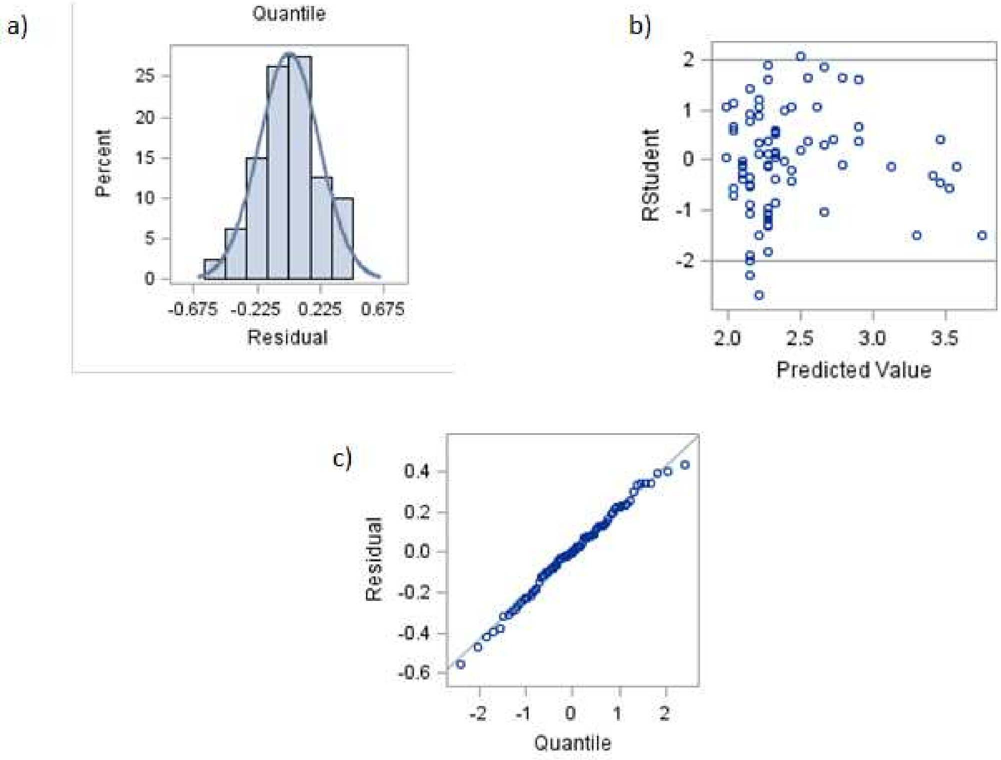


Table 3. Analysis of Variance and Parameter Estimates for the Accumulated Degree Day Model. The *p*-values for statistical significance are displayed.

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	13.32729	13.32729	285.09	<.0001
Error	78	3.64631	0.04675		
Corrected Total	79	16.97360			

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.52523	0.05812	26.24	<.0001
TBS	1	0.05703	0.00338	16.88	<.0001

Figure 7. The logarithm of Post-Mortem Interval Days plotted versus the Total Body Score. The calculated *R^2* value and linear regression equation are displayed.

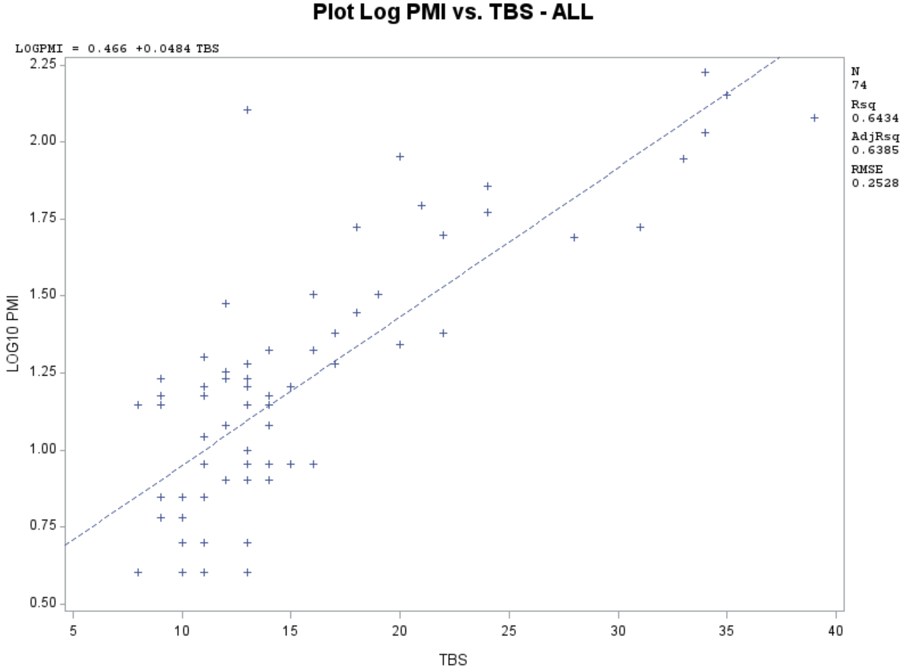


Figure 8. Depiction of the Normal Distribution of Residuals, Plot of Studentized Residuals versus Predicted Values, and the Probability Distribution of Residuals in the Post-Mortem Interval Day Model in order to satisfy the normality assumptions of linear regression analysis.

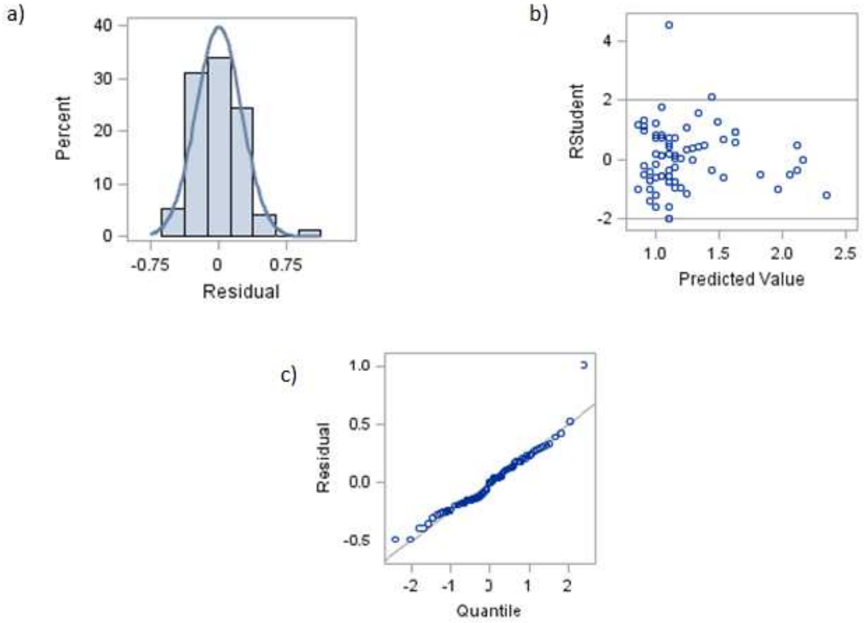
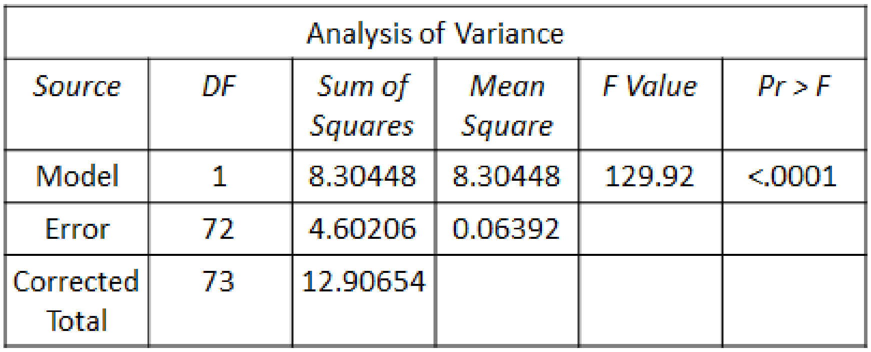
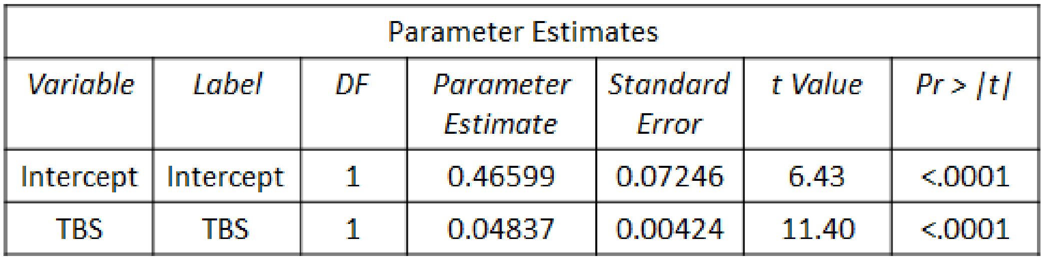


Table 4. Analysis of Variance and Parameter Estimates for the Post-Mortem Interval Day Model. The *p*-values for statistical significance are displayed.



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	8.30448	8.30448	129.92	<.0001
Error	72	4.60206	0.06392		
Corrected Total	73	12.90654			



Parameter Estimates						
Variable	*Label*	*DF*	*Parameter Estimate*	*Standard Error*	*t Value*	*Pr > |t|*
Intercept	Intercept	1	0.46599	0.07246	6.43	<.0001
TBS	TBS	1	0.04837	0.00424	11.40	<.0001

Accumulated Degree Days versus Post-Mortem Interval Days

After transforming the data, the framework for a useable model was produced. From there, in order to determine if time and temperature or time alone explains more of the variation in decomposition, the transformed accumulated degree day models were compared to the transformed post-mortem interval day models generated. This comparision included a linear regression analysis and calculation of the correlation of determination for the dataset including all cases, as well as the stratified samples broken up by depositional context and the joint non-water outdoor and indoor data points. In regards to the overall, stratified, and joint model comparisons, accumulated degree days demonstrated larger R^2 values in each and every analysis (see Figures 9 through 18). Additionally, after an analysis of variance, each of the models was deemed statistically significant except for the PMI water subset model (see Tables 5 through 14). Without question, ADD explains more of the variation in decomposition compared to PMI, and is better-suited to modeling decay and developing time since death estimation formulas. Therefore, based on this realization, ADD was chosen as the central component of the models developed.

Figure 9. Delaware River Valley Overall ADD Model Plot and Regression Equation

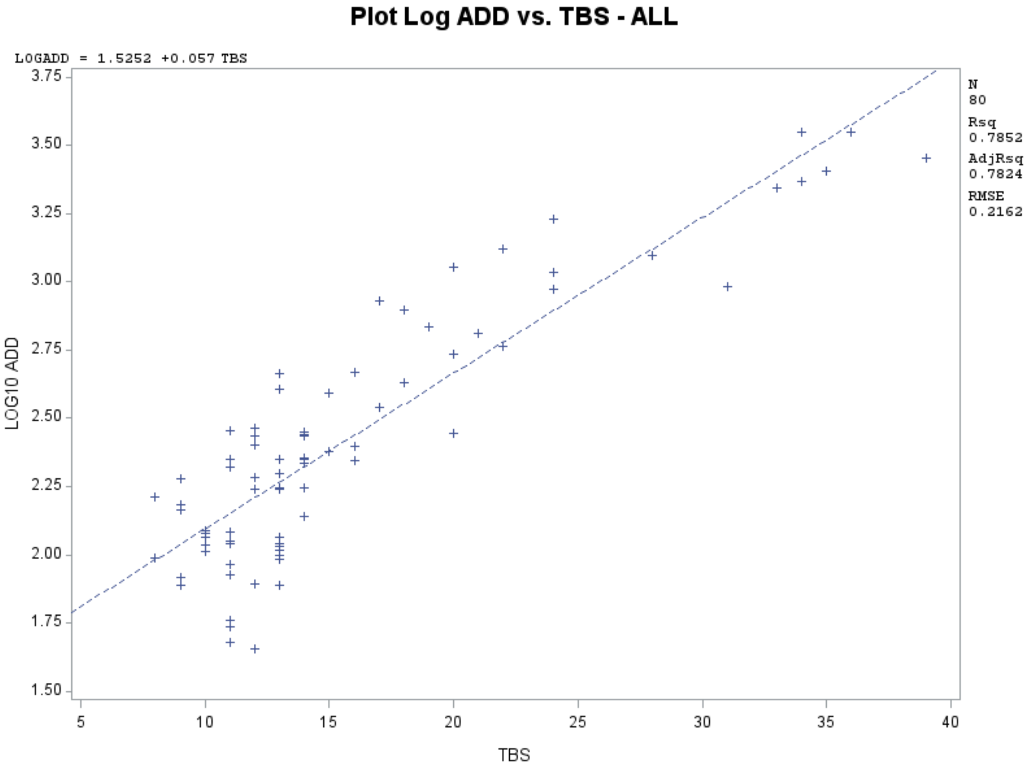
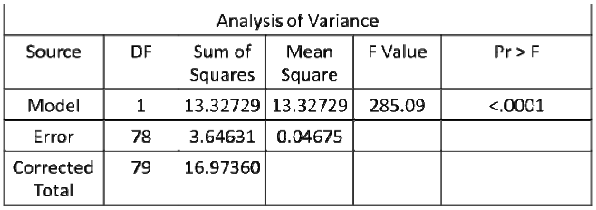


Table 5. Delaware River Valley Overall ADD Model Analysis of Variance


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	13.32729	13.32729	285.09	<.0001
Error	78	3.64631	0.04675		
Corrected Total	79	16.97360			

Figure 10. Delaware River Valley Overall PMI Model Plot and Regression Equation

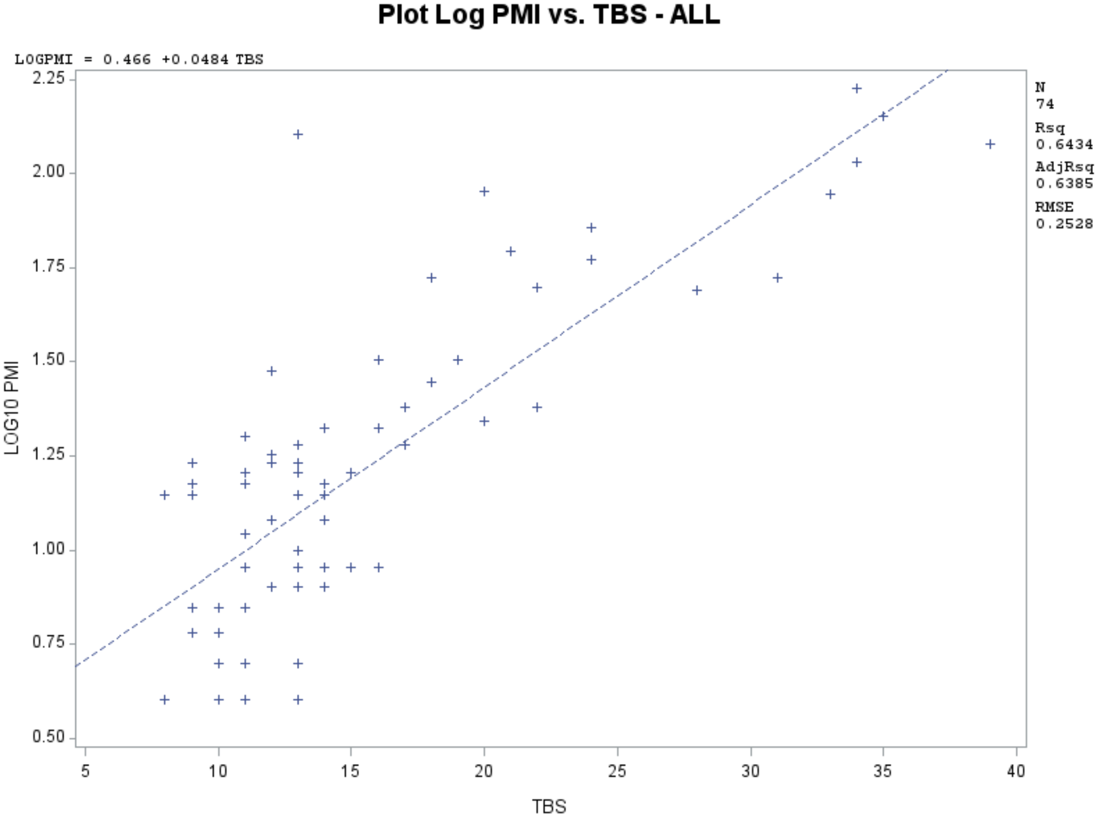


Table 6. Delaware River Valley Overall PMI Model Analysis of Variance

Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	8.30448	8.30448	129.92	<.0001
Error	72	4.60206	0.06392		
Corrected Total	73	12.90654			

Figure 11. Delaware River Valley Indoor ADD Model Plot and Regression Equation

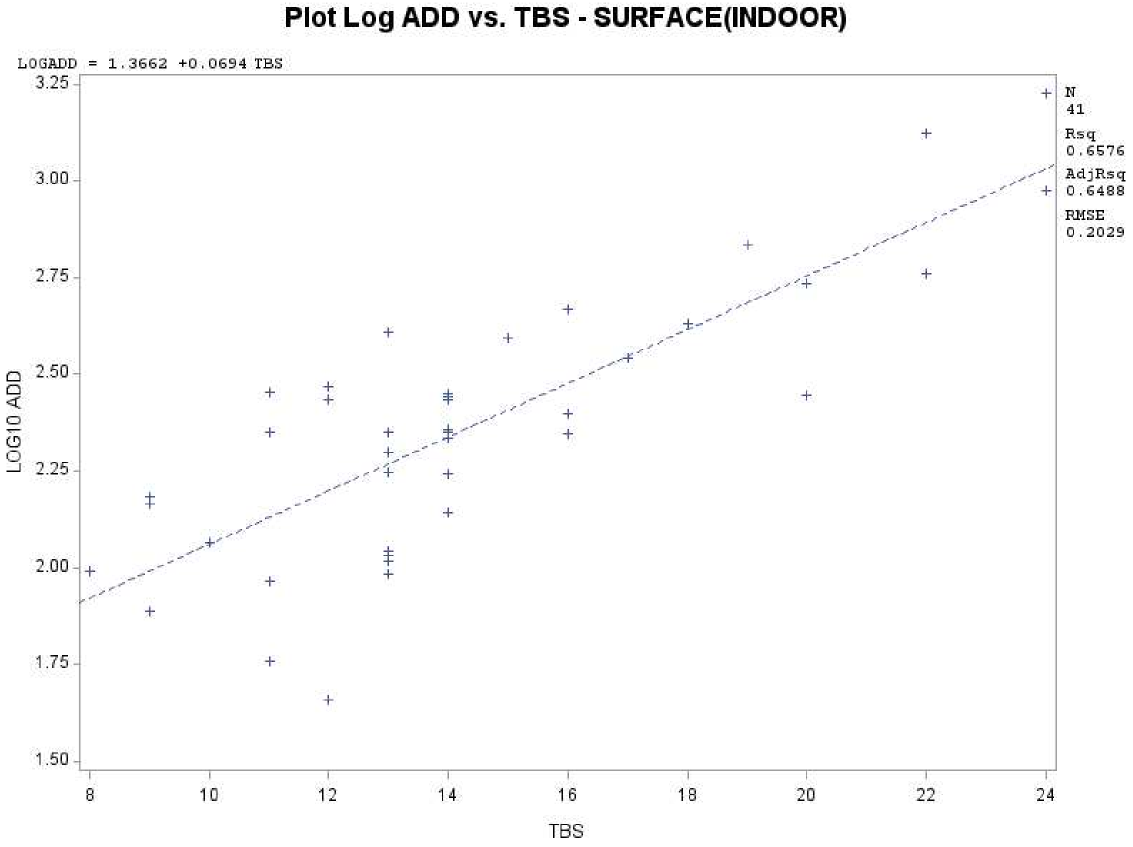


Table 7. Delaware River Valley Indoor ADD Model Analysis of Variance

Analysis of Variance

Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	3.08421	3.08421	74.89	<.0001
Error	39	1.60606	0.04118		
Corrected Total	40	4.69027			

Figure 12. Delaware River Valley Indoor PMI Model Plot and Regression Equation

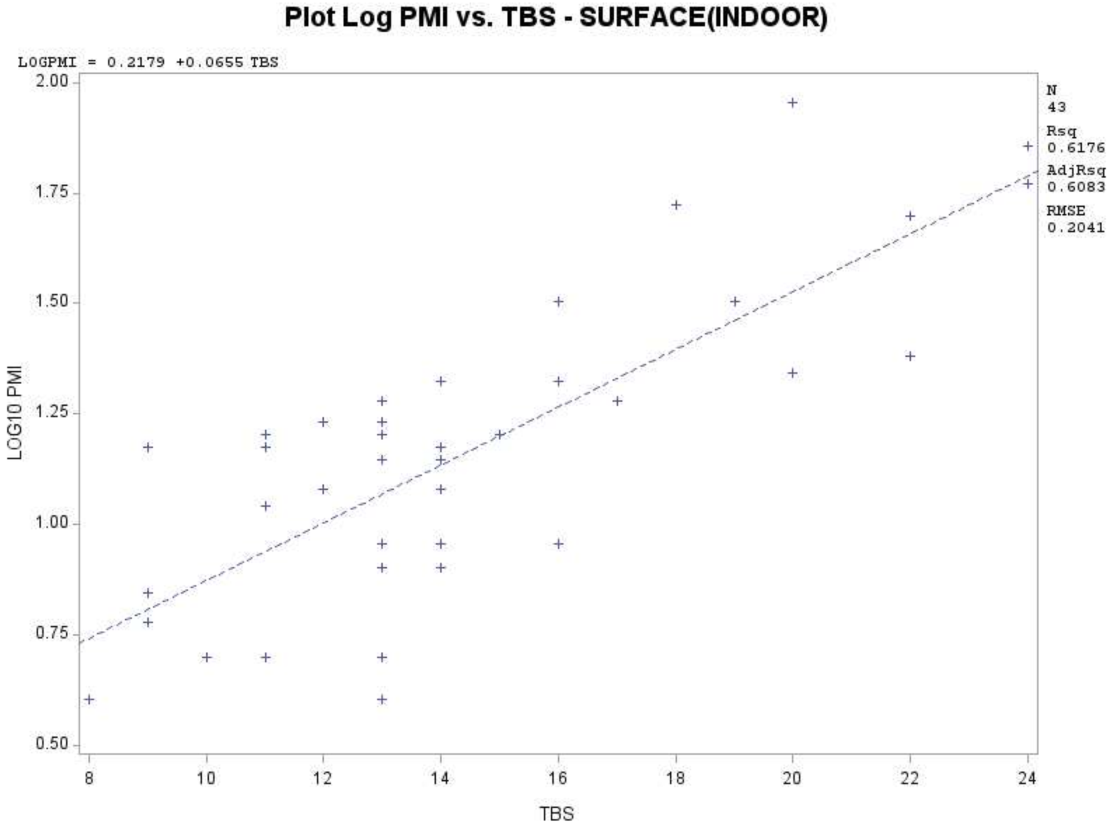
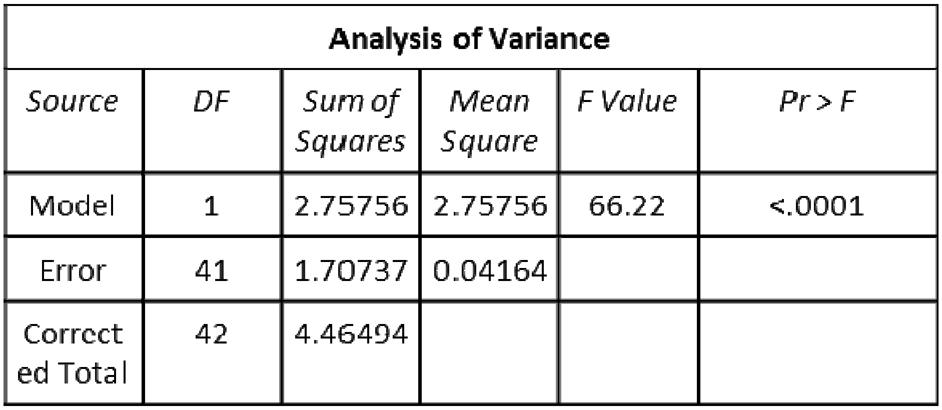


Table 8. Delaware River Valley Indoor PMI Model Analysis of Variance



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	2.75756	2.75756	66.22	<.0001
Error	41	1.70737	0.04164		
Corrected Total	42	4.46494			

Figure 13. Delaware River Valley Non-Water Outdoor ADD Model Plot and Regression Equation

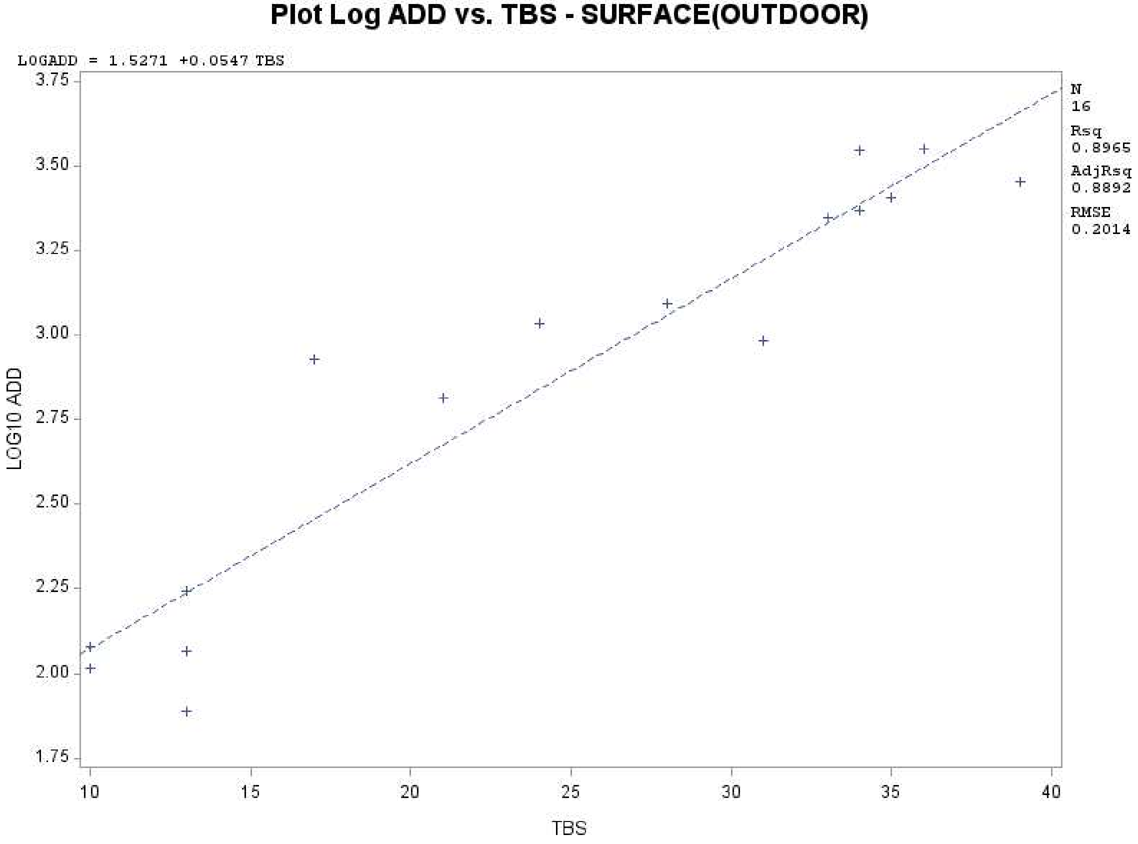
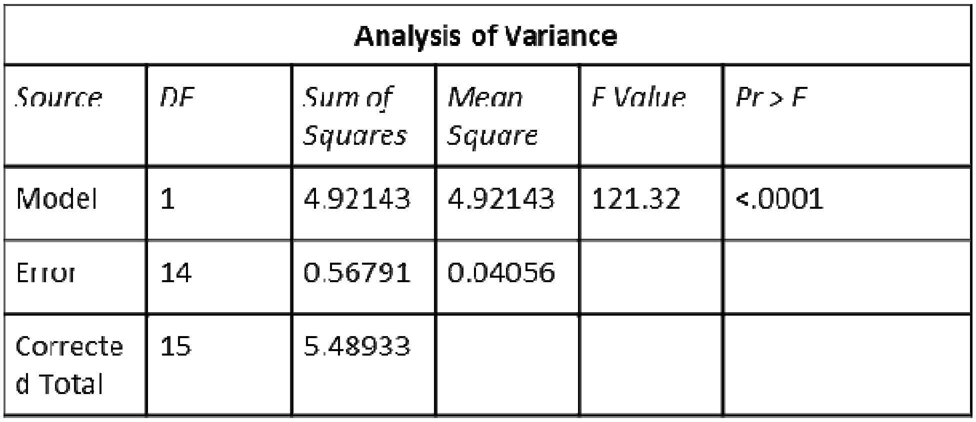


Table 9. Delaware River Valley Non-Water Outdoor ADD Model Analysis of Variance



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	4.92143	4.92143	121.32	<.0001
Error	14	0.56791	0.04056		
Corrected Total	15	5.48933			

Figure 14. Delaware River Valley Non-Water Outdoor PMI Model Plot and Regression Equation

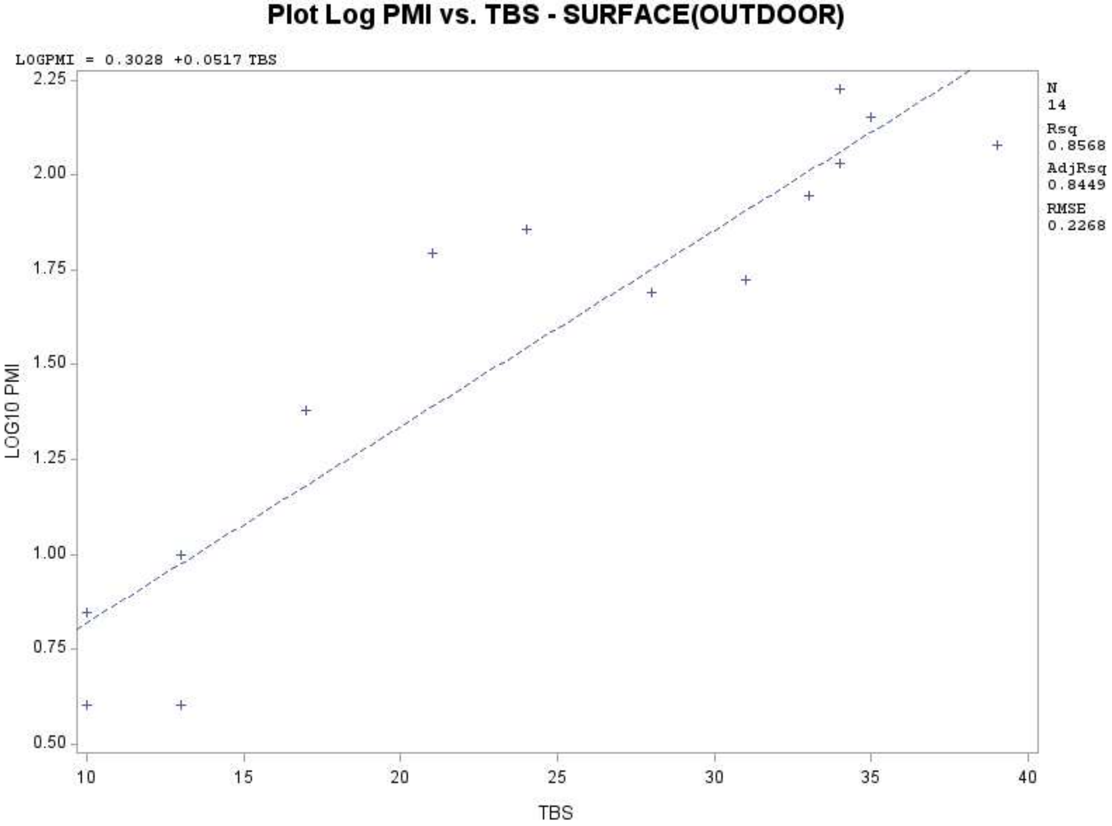
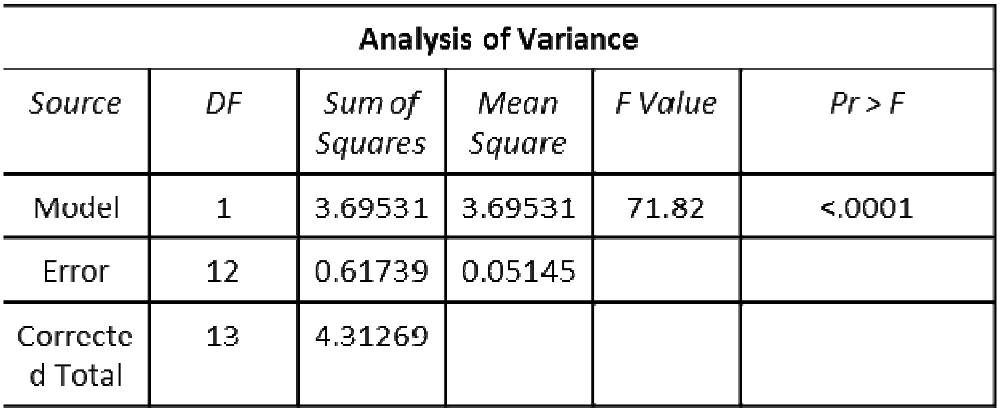


Table 10. Delaware River Valley Non-Water Outdoor PMI Model Analysis of Variance



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	3.69531	3.69531	71.82	<.0001
Error	12	0.61739	0.05145		
Corrected Total	13	4.31269			

Figure 15. Delaware River Valley Water ADD Model Plot and Regression Equation

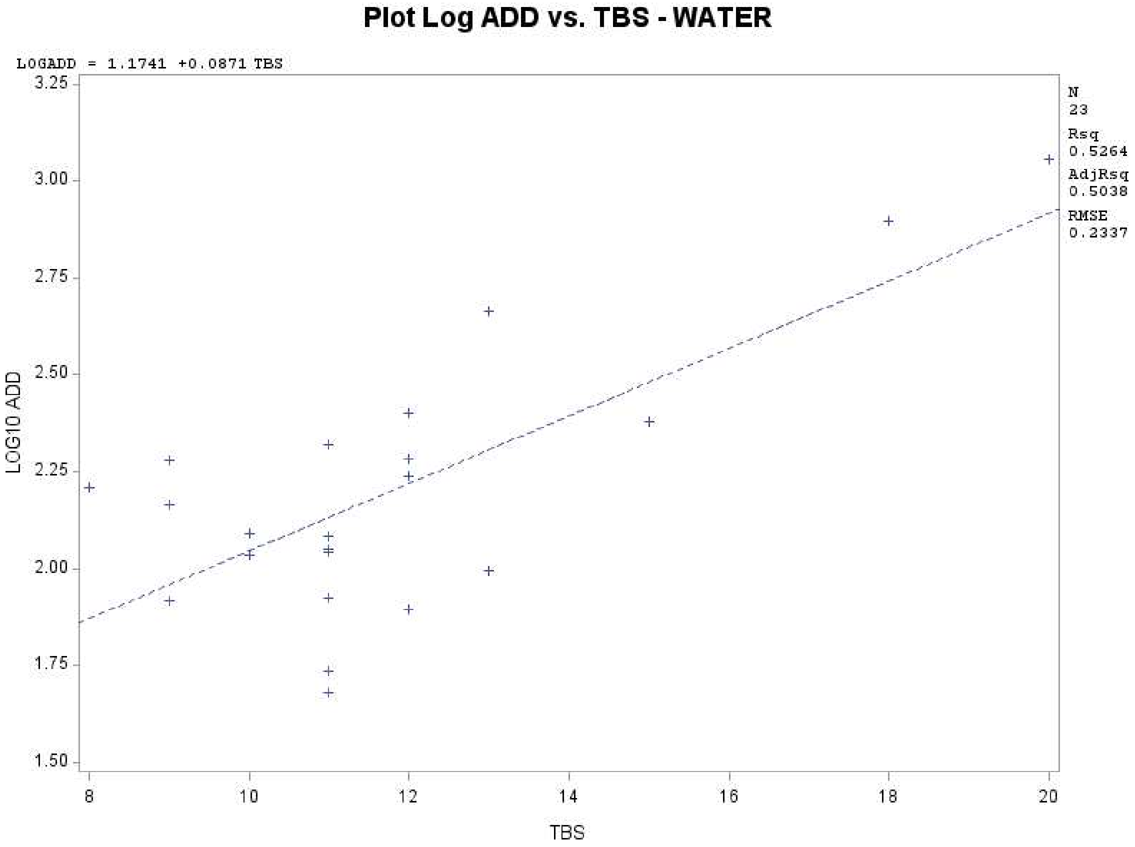


Table 11. Delaware River Valley Water ADD Model Analysis of Variance

Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	1.27530	1.27530	23.34	<.0001
Error	21	1.14741	0.05464		
Corrected Total	22	2.42271			

Figure 16. Delaware River Valley Water PMI Model Plot and Regression Equation

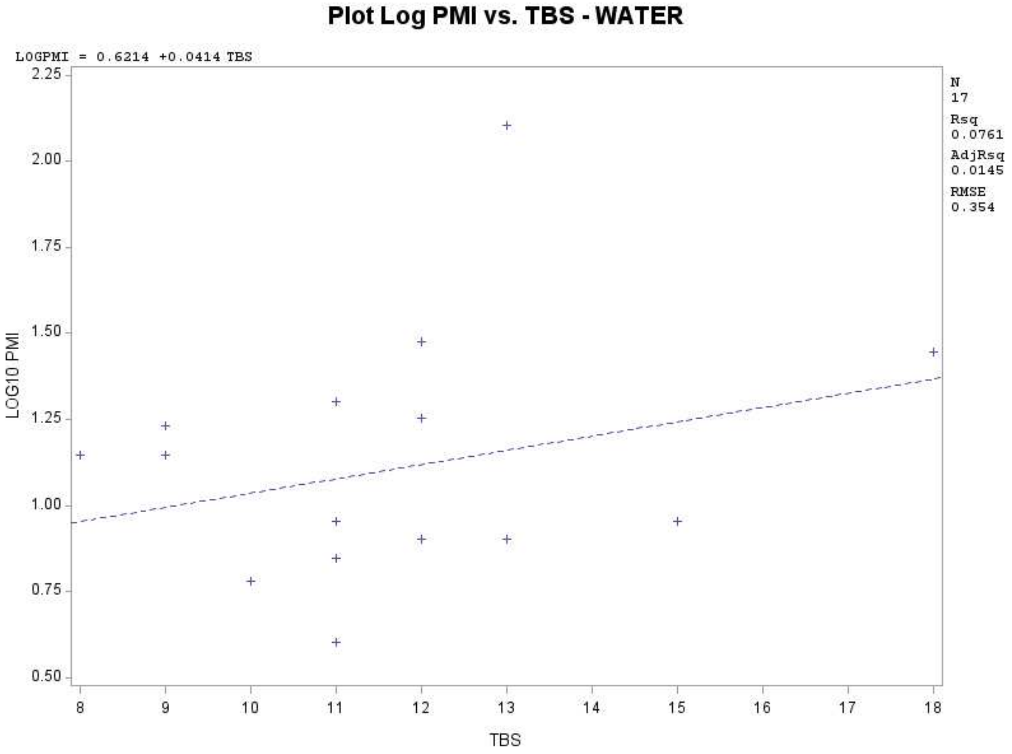
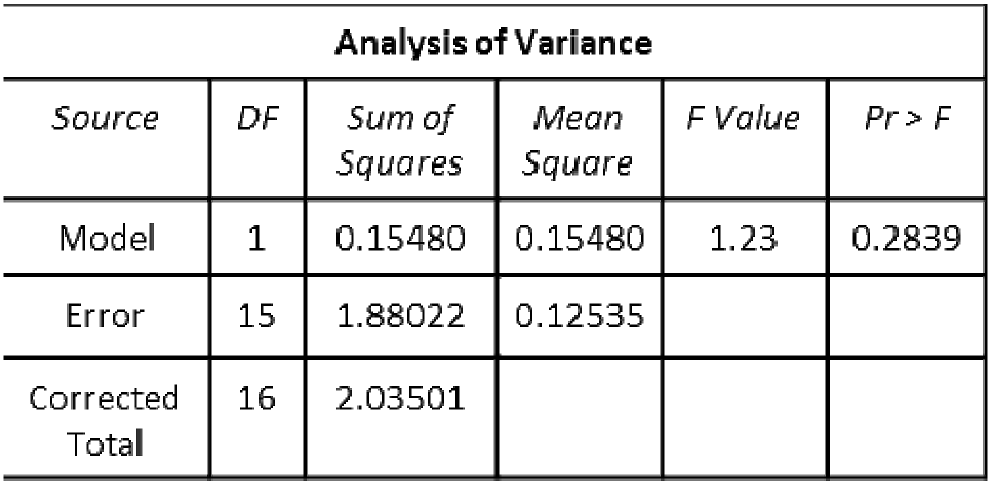


Table 12. Delaware River Valley Water PMI Model Analysis of Variance



Analysis of Variance					
Source	*DF*	*Sum of Squares*	*Mean Square*	*F Value*	*Pr > F*
Model	1	0.15480	0.15480	1.23	0.2839
Error	15	1.88022	0.12535		
Corrected Total	16	2.03501			

Figure 17. Delaware River Valley Non-Water Outdoor and Indoor ADD Model Plot and Regression Equation

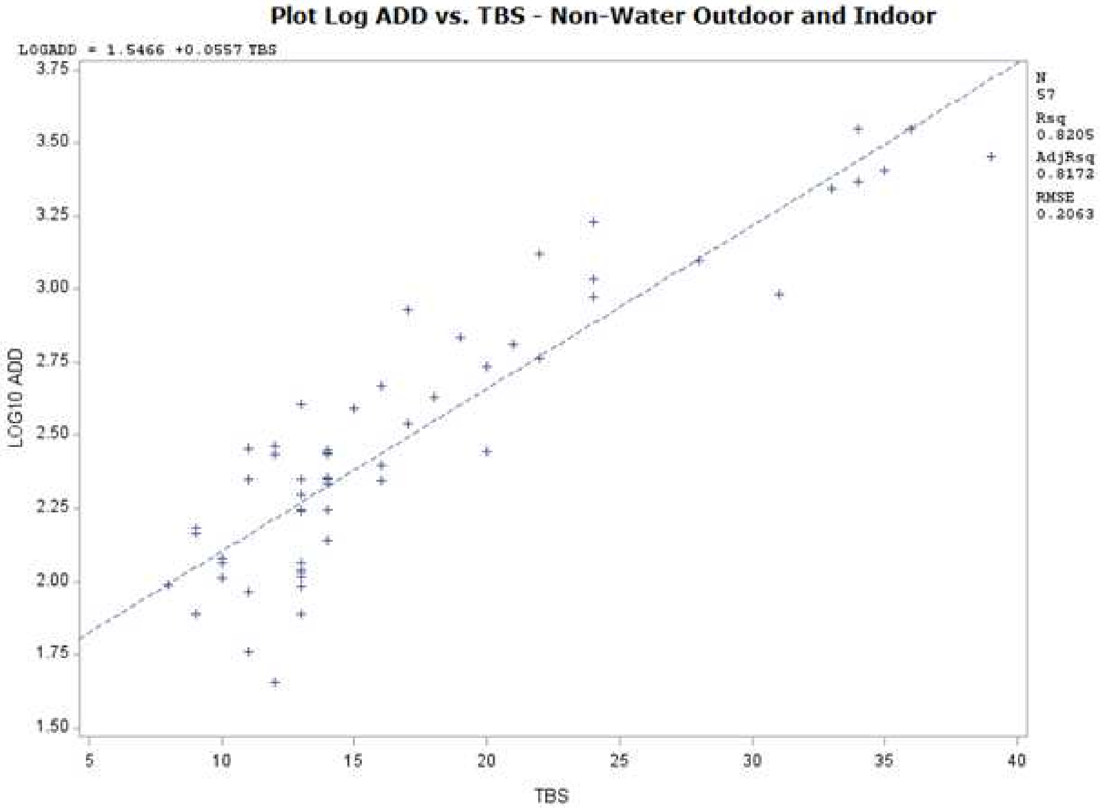
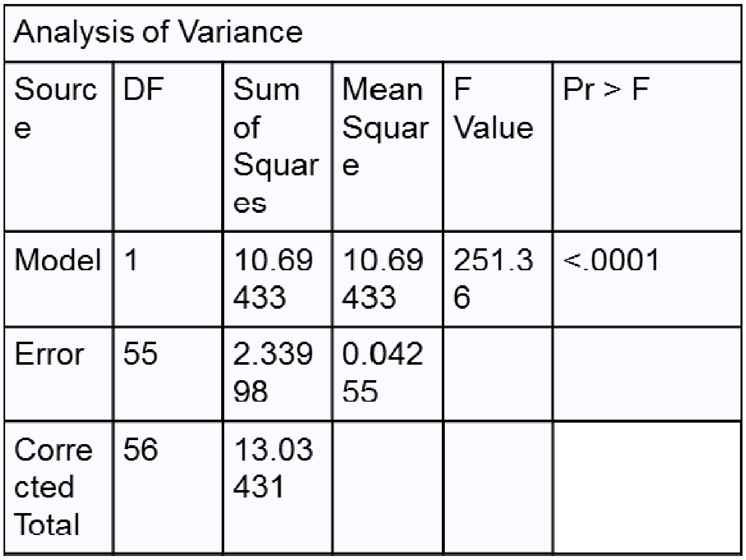


Table 13. Delaware River Valley Non-Water Outdoor and Indoor ADD Model Analysis of Variance



Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	10.69433	10.69433	251.36	<.0001
Error	55	2.33998	0.04255		
Corrected Total	56	13.03431			

Figure 18. Delaware River Valley Non-Water Outdoor and Indoor PMI Model Plot and Regression Equation

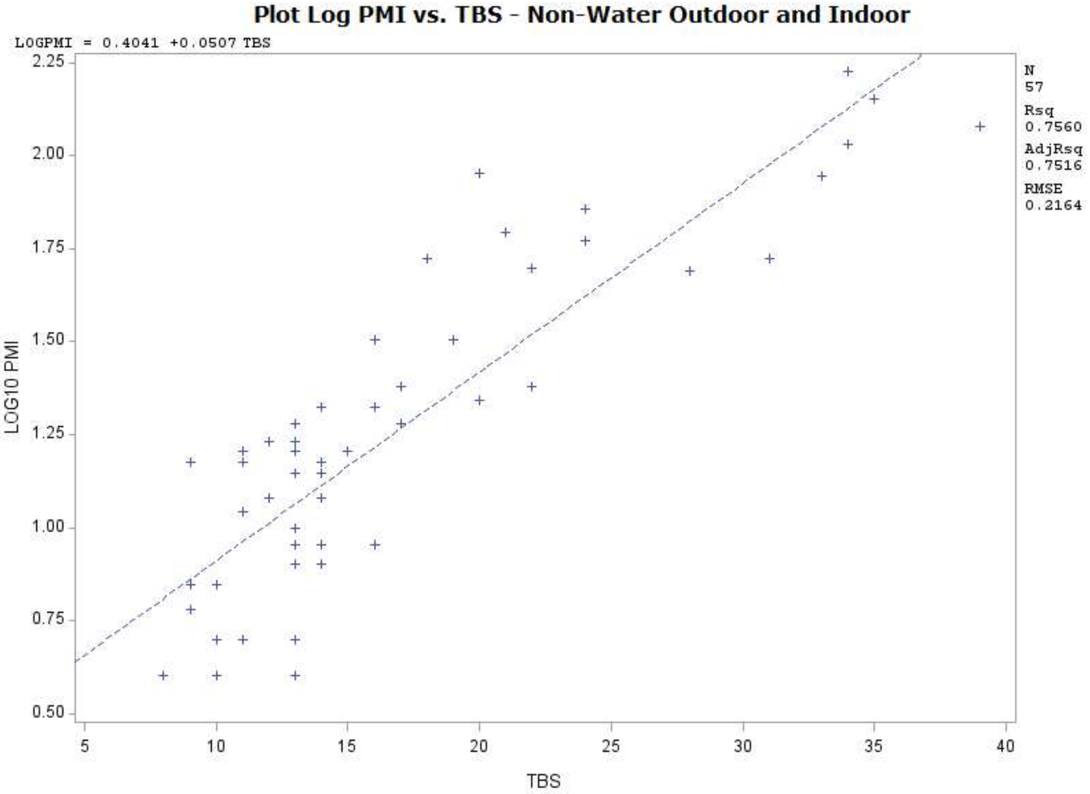
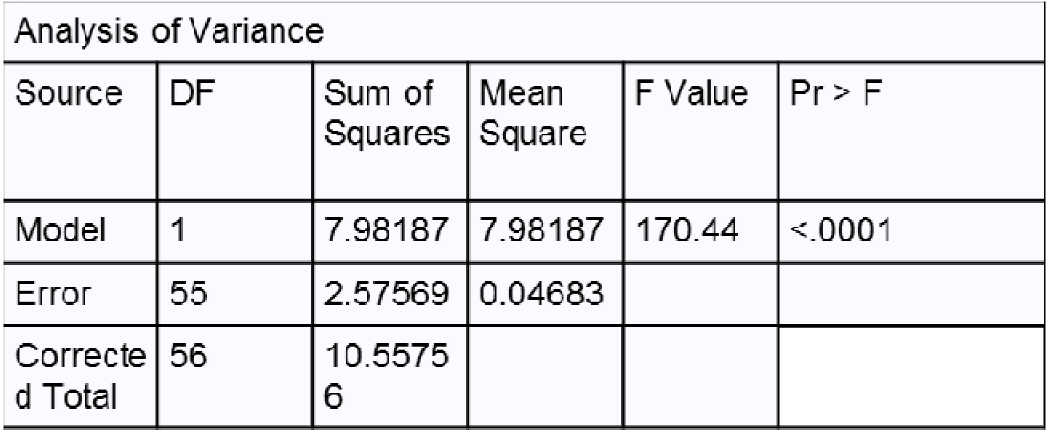


Table 14. Delaware River Valley Non-Water Outdoor and Indoor PMI Model Analysis of Variance



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	7.98187	7.98187	170.44	<.0001
Error	55	2.57569	0.04683		
Corrected Total	56	10.55756			

ADD Model Comparison

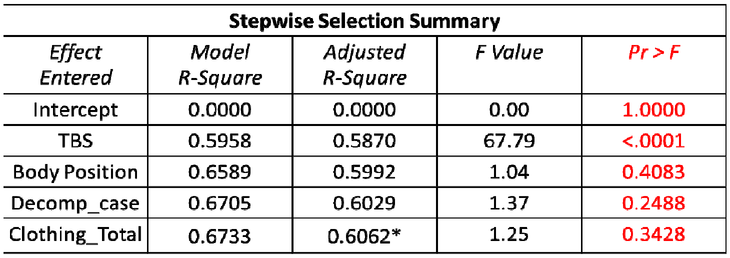
Based on the results of the overall and stratified analyses, it became clear that the overall ADD model does not explain as large a proportion of the variation in decomposition compared to the non-water outdoor and indoor ADD model (see Figures 9 and 17). This was especially true in comparison to the non-water outdoor ADD subset model alone (see Figure 13). However, given the low sample size in the non-water outdoor subset, extreme caution is advised in the use of the regression equation developed from those cases. The joint non-water outdoor and indoor model contains a much greater number of data points and thus can be used more confidently. Although the overall ADD model contains the greatest number of cases, it is hampered by the inclusion of aquatic cases. The water ADD model, due to the low proportion of variation explained in that particular depositional context, appears to be affected by confounding factors and variables which are either too difficult to track historically or are as-yet-unknown (see Figure 15). Therefore, the joint non-water outdoor and indoor model may be a better option when estimating time since death for those particular types of cases, as opposed to the overall ADD model.

Identification of Additional Covariates for Inclusion in the ADD Model

Although total body score has been demonstrated to play the single most important role in modeling decomposition by representing the decay changes which occur in an area, additional covariates were searched for in order to determine if their inclusion would increase the explanatory potential of the decomposition models derived in this study. Thus, a multivariate linear regression analysis, utilizing a stepwise selection method, was conducted on both the overall and stratified data groups.

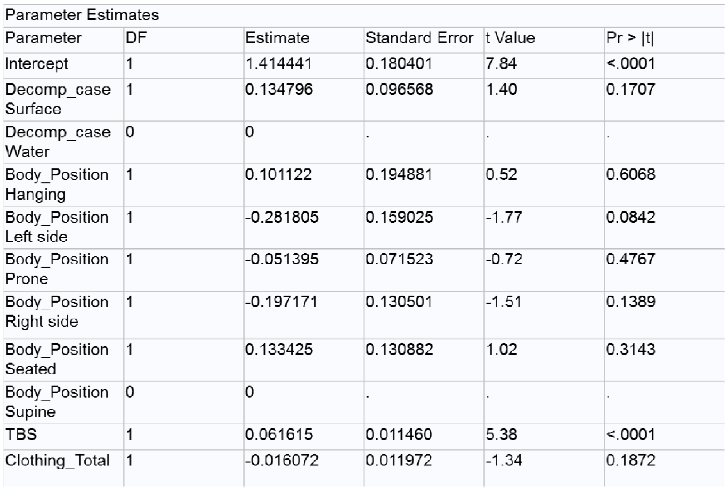
In the overall accumulated degree day model, four variables were selected based on their adjusted R^2 values. These variables included type of depositional context, clothing, total body score, and body position, with the latter encompassing supine, prone, left leaning, right leaning, seated, and hanging bodies. However, it was determined that only total body score proved to demonstrate a statistically significant effect, with a *p*-value less than 0.0001 (see Tables 15 and 16).

Table 15. Delaware River Valley Overall ADD Model Covariate Stepwise Selection



Stepwise Selection Summary				
Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
TBS	0.5958	0.5870	67.79	<.0001
Body Position	0.6589	0.5992	1.04	0.4083
Decomp_case	0.6705	0.6029	1.37	0.2488
Clothing_Total	0.6733	0.6062*	1.25	0.3428

Table 16. Delaware River Valley Overall ADD Model Covariate Parameter Estimates

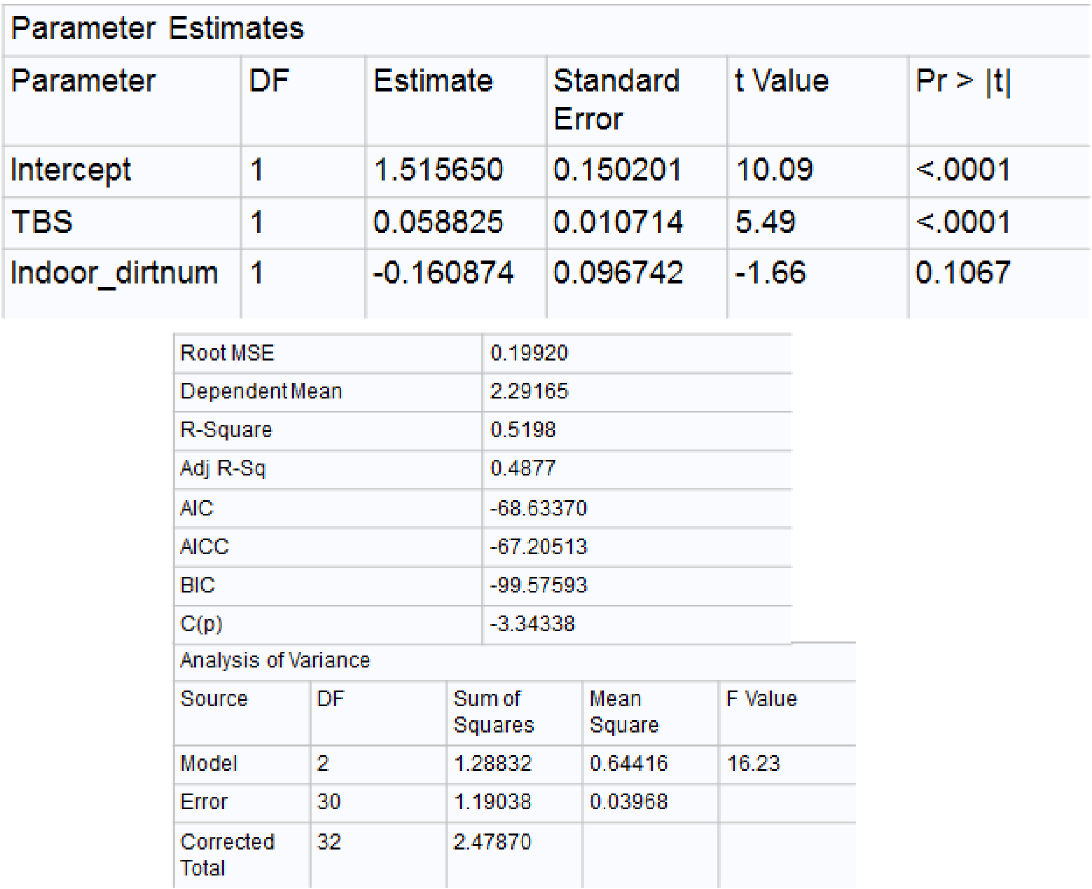


Parameter Estimates

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.414441	0.180401	7.84	<.0001
Decomp_case Surface	1	0.134796	0.096568	1.40	0.1707
Decomp_case Water	0	0	.	.	.
Body_Position Hanging	1	0.101122	0.194881	0.52	0.6068
Body_Position Left side	1	-0.281805	0.159025	-1.77	0.0842
Body_Position Prone	1	-0.051395	0.071523	-0.72	0.4767
Body_Position Right side	1	-0.197171	0.130501	-1.51	0.1389
Body_Position Seated	1	0.133425	0.130882	1.02	0.3143
Body_Position Supine	0	0	.	.	.
TBS	1	0.061615	0.011460	5.38	<.0001
Clothing_Total	1	-0.016072	0.011972	-1.34	0.1872

In the joint non-water outdoor and indoor model, total body score was also determined to produce a statistically significant effect. Although dirty versus clean environments was also selected due to the high proportion of variation it explains, its effect was not statistically significant (see Table 17).

Table 17. Delaware River Valley Non-Water Outdoor and Indoor ADD Model Covariate Parameter Estimates and Analysis of Variance



Parameter Estimates

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.515650	0.150201	10.09	<.0001
TBS	1	0.058825	0.010714	5.49	<.0001
Indoor_dirtnum	1	-0.160874	0.096742	-1.66	0.1067

Root MSE	0.19920
Dependent Mean	2.29165
R-Square	0.5198
Adj R-Sq	0.4877
AIC	-68.63370
AICC	-67.20513
BIC	-99.57593
C(p)	-3.34338

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value
Model	2	1.28832	0.64416	16.23
Error	30	1.19038	0.03968	
Corrected Total	32	2.47870		

In regards to the indoor subset, total body score was once again identified as producing a statistically significant effect. Although insect activity and the cleanliness of the indoor environments were also selected based on their adjusted R^2 values, their effects were not deemed to be statistically significant (see Tables 18 and 19).

Table 18. Delaware River Valley Indoor ADD Model Covariate Stepwise Selection

Stepwise Selection Summary				
Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
TBS	0.4755	0.4586	28.10	<.0001
Indoor_dirtnum	0.5198	0.4877	2.77	0.1067
Insect_total	0.5414	0.4939*	1.37	0.2519

Table 19. Delaware River Valley Indoor ADD Model Covariate Parameter Estimates

Parameter Estimates					
Parameter	*DF*	*Estimate*	*Standard Error*	*t Value*	Pr > |t|
Intercept	1	1.522660	0.149411	10.19	<.0001
TBS	1	0.054015	0.011417	4.73	<.0001
Indoor_dirtnum	1	-0.152005	0.096455	-1.58	0.1259
Insect_total	1	0.019425	0.016615	1.17	0.2519

Interestingly, in the non-water outdoor subset, total body score dropped out as a statistically significant variable (see Tables 20 and 21). The same was observed in the water subset as well (see Tables 22 and 23).

Table 20. Delaware River Valley Non-Water Outdoor ADD Model Covariate Stepwise Selection

Stepwise Selection Summary

Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
Precip	0.9297	0.8946	26.46	0.0358
Trauma_total	0.9911	0.9734*	6.93	0.2311

Table 21. Delaware River Valley Non-Water Outdoor ADD Model Parameter Estimates

Parameter Estimates

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.418331	0.191963	7.39	0.0856
Precip	1	0.134969	0.020207	6.68	0.0946
Trauma_total	1	0.527154	0.200275	2.63	0.2311

Table 22. Delaware River Valley Water ADD Model Covariate Stepwise Selection

Stepwise Selection Summary

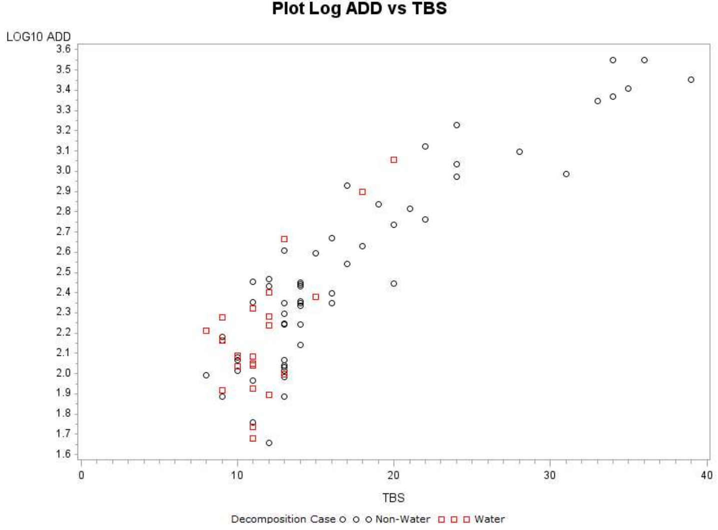
Effect Entered	*Model R-Square*	*Adjusted R-Square*	*F Value*	*Pr > F*
Intercept	0.0000	0.0000	0.00	1.0000
Outside_Sun	0.5698	0.4623	5.30	0.0828
Scav_total	0.8708	0.7846	6.99	0.0774
Age	0.9890	0.9725	21.52	0.0435
Clothing_Total	0.9991	0.9953*	10.77	0.1883

Table 23. Delaware River Valley Water ADD Model Covariate Parameter Estimates

Parameter Estimates					
Parameter	*DF*	*Estimate*	*Standard Error*	*t Value*	Pr > |t|
Intercept	1	1.910331	0.034013	56.16	0.0113
Outside_Sun	1	-0.567586	0.019521	-29.08	0.0219
Age	1	0.008115	0.000765	10.61	0.0598
Clothing_Total	1	0.014009	0.004269	3.28	0.1883
Scav_total	1	0.182753	0.011753	15.55	0.0409

However, one should not be alarmed by these finds. Given the known role played by total body score, as well as its identification as a statistically significant variable in the larger sample sets, its effect is known and understood. In fact, the continuous plot of the logADD versus TBS affirms the relationship between total body score and accumulated degree days, demonstrating the same relationship across each and every depositional context (see Figure 19).

Figure 19. Continuous Plot of Log ADD vs. TBS



On the otherhand however, very few of the remaining variables demonstrate any distinguishable relationships with accumulated degree days. Although precipitation shows a noticeable trend, its impact may already be accounted for, in part, in the accumulated degree days themselves, especially considering the relationship between precipitation, humidity, and temperature. Insect activity may also indicate a pattern, however many more cases would be needed to extract information regarding that relationship. The remaining variables either show no relationship at all, or are plagued by sample size and the binary nature of the data collection efforts (see Figures 20 through 29).

Figure 20. Continuous Plot of Log ADD vs. Soil pH

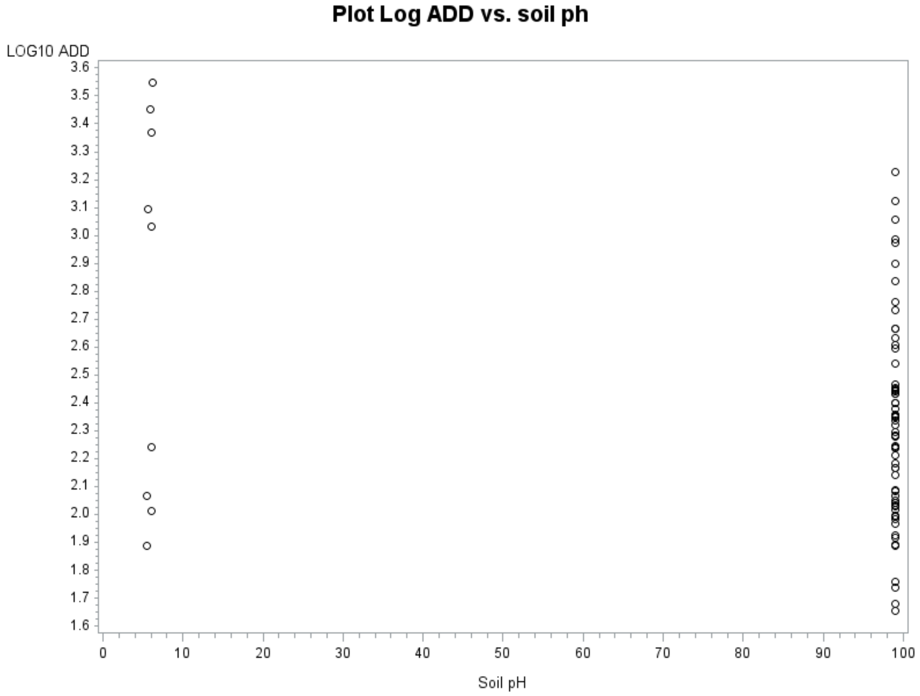


Figure 21. Continuous Plot of Log ADD vs. Salinity Level

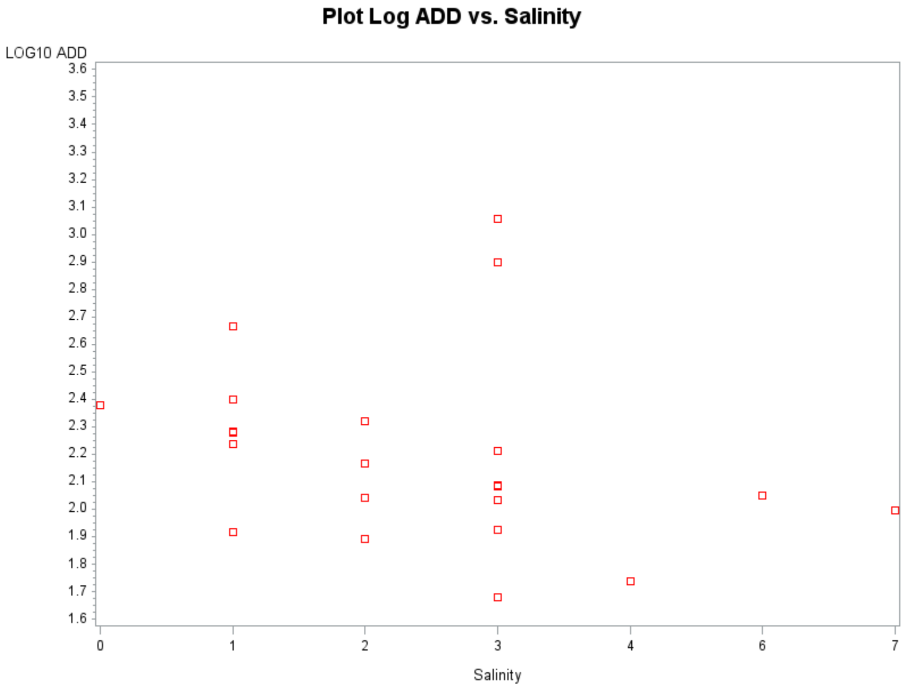


Figure 22. Continuous Plot of Log ADD vs. Precipitation

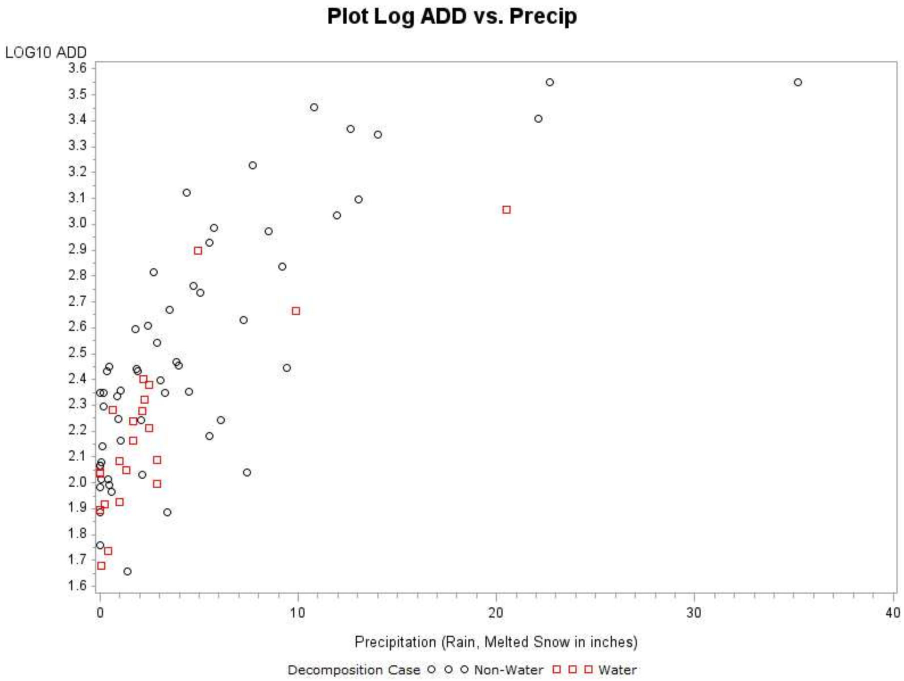


Figure 23. Continuous Plot of Log ADD vs. Age

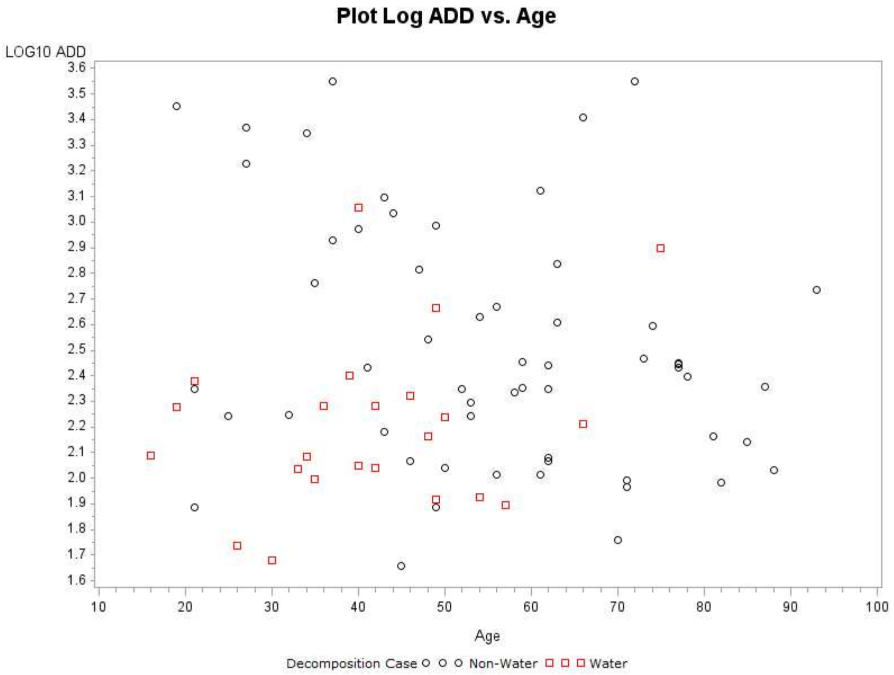


Figure 24. Continuous Plot of Log ADD vs. Height

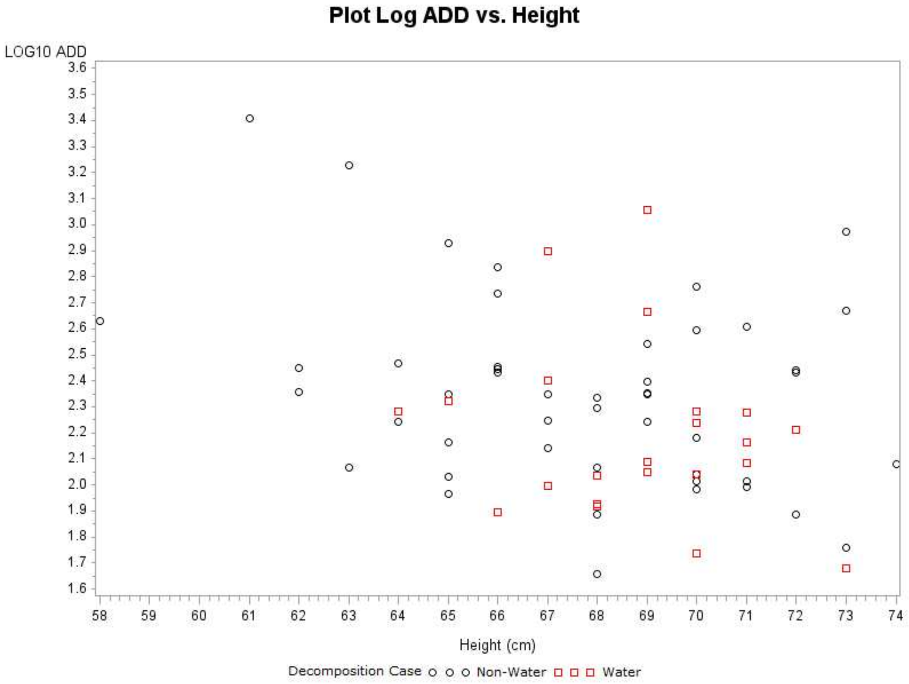


Figure 25. Continuous Plot of Log ADD vs. Weight

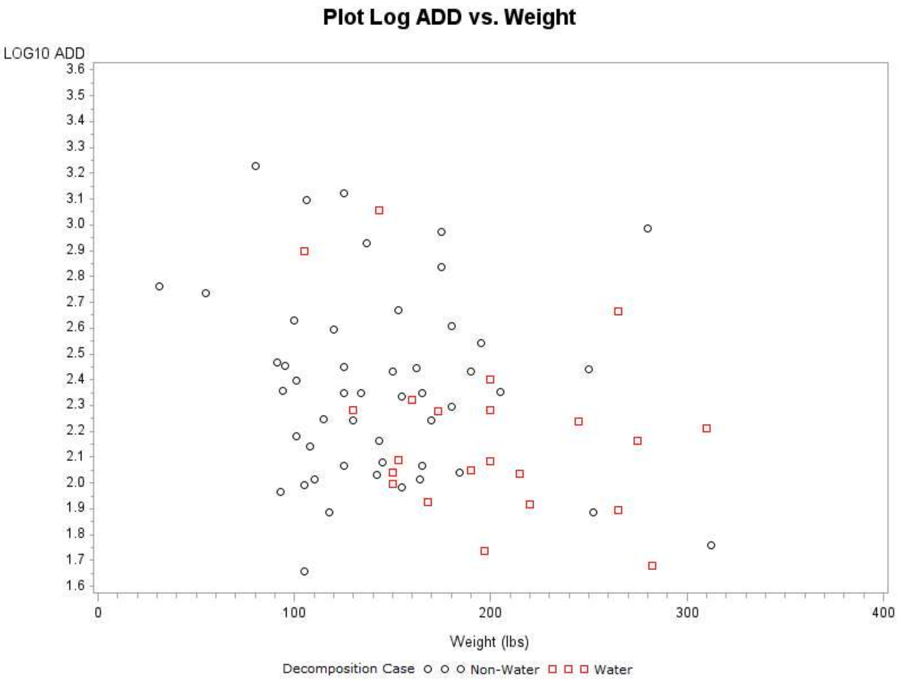


Figure 26. Continuous Plot of Log ADD vs. Clothing Total

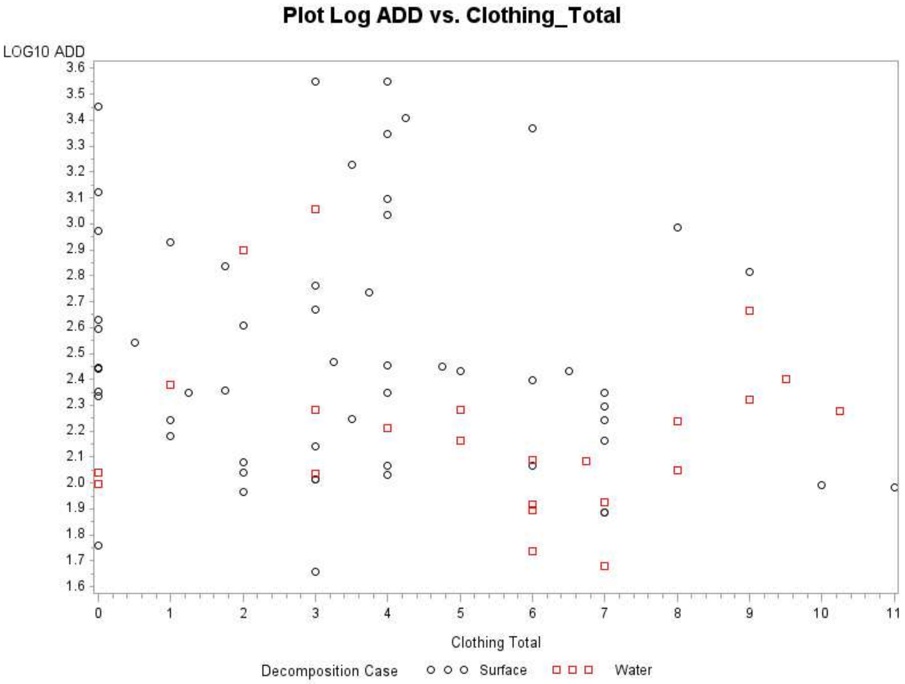


Figure 27. Continuous Plot of Log ADD vs. Insect Activity

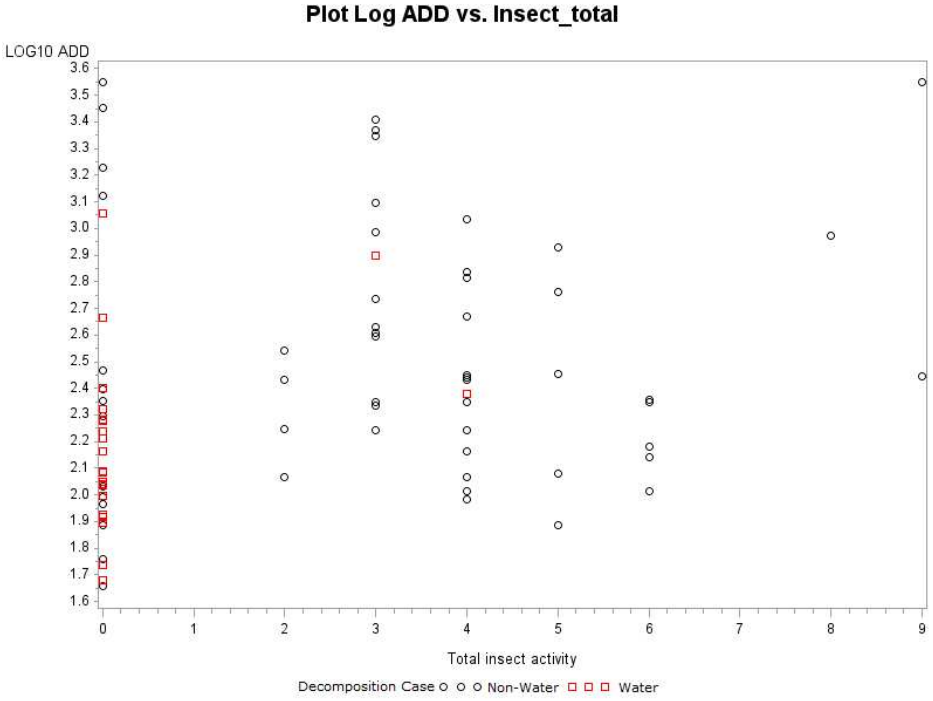


Figure 28. Continuous Plot of Log ADD vs. Trauma

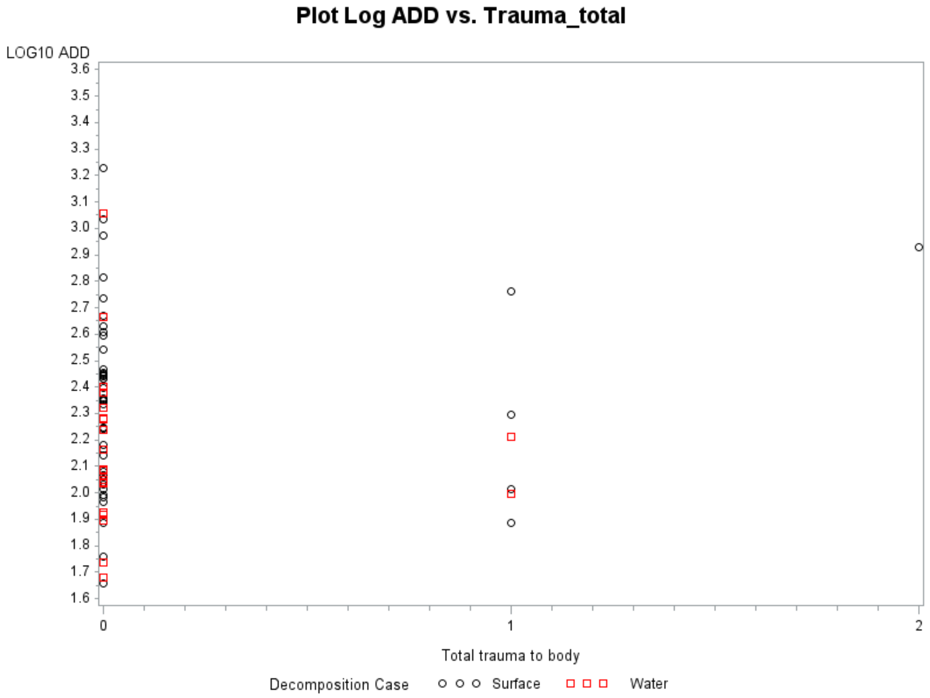
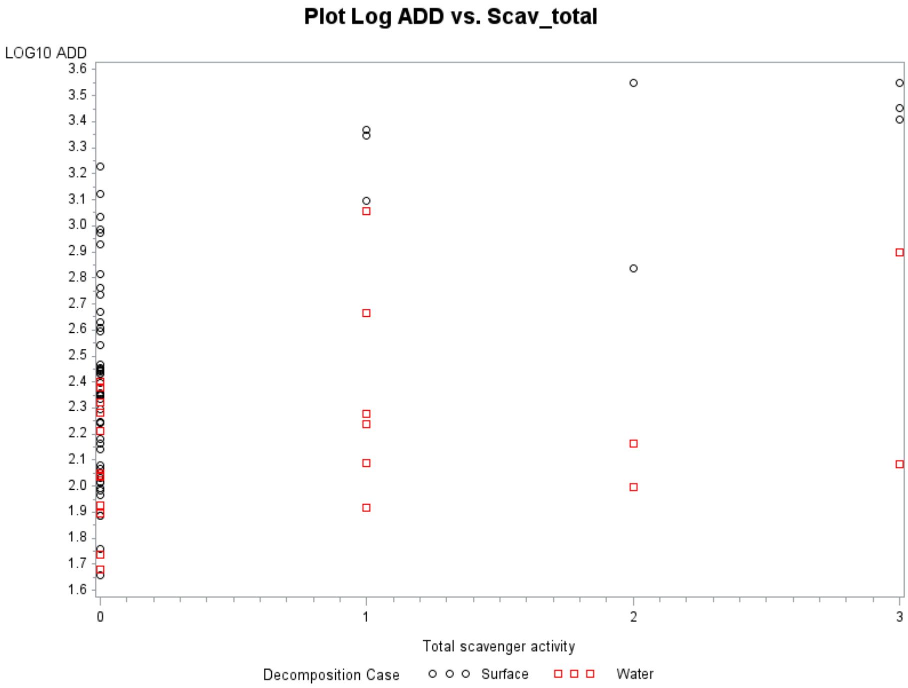


Figure 29. Continuous Plot of Log ADD vs. Scavenging



Furthermore, in the case of the non-water outdoor subset, the reason for the results produced has much less to do with the effects of variables and more to do with the sample size utilized in the analysis. Unfortunately, given the subdivided nature of these stratified analyses, sample sizes were generally too low to identify any meaningful trends. Variables, which may typically have demonstrated a statistically significant effect, may not have been selected given the low sample sizes at this subdivided level of analysis. This was especially true of the non-water outdoor context, where only 16 cases comprised the subset.

Moreover, in terms of the aquatic subset, it appears as if the trends and relationships observed are complicated by the presence of confounding factors and variables which could not be included in the analysis due to practical reasons. Many variables known to alter decay in aquatic contexts, such as tides, currents, water depth, and so forth, are not susceptible to inclusion in retroactive studies. As a result, variables which may typically not have demonstrated a statistically significant effect were selected, while others were not.

Most importantly, as stated above, given the fact that the most useful of all the models developed are the overall and joint non-water outdoor and indoor models, and that the total body score was determined to be the only statistically significant variable in the multivariate regression analyses conducted on both datasets, the role played by TBS in the regression formulas was affirmed. Therefore, based on this determination, it was decided that TBS and ADD alone would make up the two central components of the time since death estimation equations developed.

Role Played by Variables on the Rate of Decay (TBS/ADD)

Much like the observations made in regards to the statistically significant covariates identified in the stepwise selection detailed above, the analysis of the role played by various factors on the rate of decay was hampered by sample size and the nature of cross-sectional studies, once again failing to identify additional covariates beyond total body score to include in the model.

In order to determine the effects of various factors on the rate of decay, the total body score was divided by the accumulated degree days in each case demonstrating the variable in question. The average rate of decay was then taken for each variable and compared to its dichotomous counter-part. However, counter-intuitive finds were made in regards to the effects of scavenging activity, insect presence, and soil pH. All other variables were deemed to not affect the rate of decay in a statistically significant manner (see Table 24).

Table 24. Rate of Decay (TBS/ADD) Demonstrated by Each Variable

1. Dirty vs. Clean House
    a. ADD rate (TBS/ADD)

	Mean	95% CL Mean	p-value
Clean	0.0744	0.0570 0.0918	0.22
Dirty	0.0772	0.0246 0.1299	

2. Shaded vs. Exposed Remains
    a. ADD

	Mean	95% CL Mean	p-value
Exposed	0.0836	0.0536 0.1136	0.0995
Shaded	0.0536	0.0315 0.0756	

3. Trauma vs. No Trauma
    a. ADD

	Mean	95% CL Mean	p-value
No Trauma	0.0792	0.0666 0.0919	0.9118
Trauma	0.0814	0.0317 0.1311	

4. Insect vs. No Insects
    a. ADD

	Mean	95% CL Mean	p-value
No insects	0.0890	0.0683 0.1098	0.0035
Insects	0.0562	0.0457 0.0668	

5. Clothed vs. Not Clothed
    a. ADD

	Mean	95% CL Mean	p-value
No Clothes	0.0663	0.0331 0.0995	0.7315
Clothes	0.0718	0.0595 0.0842	

6. Soil pH Below 5.5 vs. Soil pH Above 5.5
    a. ADD

	Mean	95% CL Mean	p-value
≤5.5	0.0291	0.000014 0.0581	0.0351
>5.5	0.0744	0.0626 0.0862	

7. Scavenging vs. No Scavenging
    a. ADD

	Mean	95% CL Mean	p-value
No Scavenging	0.0784	0.0651 0.0917	0.0104
Scavenging	0.0437	0.0248 0.0625	

8. Supine (0) vs. Prone
    a. ADD

	Mean	95% CL Mean	p-value
Supine	0.0706	0.0548 0.0864	0.8724
Prone	0.0727	0.0484 0.0971	

9. Supine (0) vs. Seated
    a. ADD

	Mean	95% CL Mean	p-value
Supine	0.0706	0.0548, 0.0864	0.2922
Seated	0.0623	0.0608 0.0638	

10. Supine (0) vs. Hanging
    a. ADD

	Mean	95% CL Mean	p-value
Supine	0.0706	0.0548, 0.0864	0.0949
Hanging	0.0198	-0.0519 0.0916	

11. Prone (0) vs. Seated
    a. ADD

	Mean	95% CL Mean	p-value
Prone	0.0727	0.0484 0.0971	0.3795
Seated	0.0623	0.0608 0.0638	

12. Prone (0) vs. Hanging
    a. ADD

	Mean	95% CL Mean	p-value
Prone	0.0727	0.0484 0.0971	0.1647
Hanging	0.0198	-0.0519 0.0916	

13. Seated (0) vs. Hanging
    a. ADD

	Mean	95% CL Mean	p-value

Seated	0.0623	0.0608 0.0638	0.0832
Hanging	0.0198	-0.0519 0.0916	

14. Water Salinity Medium and Below vs. Water Salinity High-Medium and Above
    a. ADD

	Mean	95% CL Mean	p-value
Medium and below	0.0682	0.0570 0.0793	0.1284
High-medium and above	0.1436	0.0118 0.2754	

15. Female (2) vs. Male (1)
    a. ADD

	Mean	95% CL Mean	p-value
Male	0.0726	0.0599 0.0852	0.62
Female	0.0659	0.0385 0.0934	

16. Below Age 50 (0) vs. Above Age 50 (1)
    a. ADD

	Mean	95% CL Mean	p-value
<50	0.0714	0.0524 0.0905	0.9378
50+	0.0705	0.0574 0.0837	

17. Below 6’0” (0) vs. Above 6’0” (1)
    a. ADD

	Mean	95% CL Mean	p-value
<6’0”	0.0676	0.0567 0.0786	0.2877
6’0” +	0.0976	0.0379 0.1573	

Despite these results, these particular finds are directly tied to the low sample sizes observed within these groups, as well as the inability to control for when the various factors “entered” into the study and the time required to recover each body. Additionally, given the fact that the time between the “date last seen” and the “date recovered” is not always going to accurately reflect the exact post-mortem interval during which a body was left exposed to the elements, this particular consideration may also have served to produce these counter-intuitive relationships. Lastly, the presence of particular variables may have been masked by the environments in which the bodies were left to decompose. For example, in regards to insect activity, their presence may have been obliterated by severe weather, carnivore consumption, tides, currents, and so forth. What's more, insects may have contributed to the breakdown of soft tissues, but once all tissues were consumed, they may have migrated away from the corpse. As a result, it appeared as if insects did not contribute to advancing the body to the skeletonization stage.

In total, based on all of these factors, not much could be said of the results observed, therefore precluding the inclusion of additional variables into the models. Much larger sample sizes, with variables demonstrating similar or equal total body scores and accumulated degree day ranges are needed to facilitate such comparisons. When these results are coupled with the finds of the multivariate regression analyses conducted and the examination of the continuous plots produced, it is clear that only TBS warrants inclusion as a variable in the models.

Role Played by Depositional Contexts on the Rate of Decay (TBS/ADD)

Continuing on with the analysis of the rate of decay, the results of the comparisons of the depositional contexts also produced counter-intuitive finds. The exact same methods were employed to conduct the analyses, including the comparison of the average TBS over ADD in each environment, yielding similar concerns.

Based on the work of Maples and Browning (1994), it has long been believed that outdoor decomposition progresses at a much faster rate than water decomposition. Indoor decay is believed to fall somewhere in the middle, demonstrating a slightly slower rate of decay than outdoor decomposition. However, when the rates were compared between contexts, bodies exposed to outdoor environments appeared to demonstrate a mean rate close to two times as slow as water environments. This difference was deemed statistically significant. Additionally, in the comparison between indoor and outdoor contexts, the outdoor context once again showed a slower rate of decay, although the relationship was significant only at the 0.10 level (see Table 25).

Table 25. Rate of Decay (TBS/ADD) Demonstrated by Each Depositional Context

1. Indoor (0) vs. Outdoor (Surface)
    a. ADD

	Mean	95% CL Mean		p-value
Outdoor	0.0463	0.0213	0.0713	0.0783
Indoor	0.0716	0.0564	0.0868	

2. Indoor vs. Water → Indoor (surface) vs ALL water cases
    a. ADD

	Mean	95% CL Mean		p-value
Indoor	0.0716	0.0564	0.0868	0.2409
Water	0.0871	0.0638	0.1103	

3. Outdoor vs. Water→ Outdoor (surface) vs ALL water cases
    a. ADD

	Mean	95% CL Mean		p-value
Outdoor	0.0463	0.0213	0.0713	0.0191
Water	0.0871	0.0638	0.1103	

However, despite the obvious counter-intuitive results found, much of it can be explained away by the nature of the dataset in each depositional context. Significant differences were found in the range of total body scores and accumulated degree days in each subset. In particular, when comparing the non-water outdoor cases to indoor cases, the average total body score in the outdoor cases was seen to be nearly twice as large as the mean TBS in the indoor cases. The average ADD in the outdoor cases was over three times as large as in the indoor cases. Given these critical differences, they essentially handicapped the outdoor dataset, accounting for the slower rate of decay observed. Additionally, given the different total body score systems utilized between non-water and aquatic cases, this also contributed to the counter-intuitive results produced. Therefore, the only reliable method in which to compare the rate of decay between depositional contexts, would require cases which demonstrated similar total body scores, not only with similar total body scoring systems, but with similar total decomposition.

Unfortunately, based on the inability to control the total body scores in this study and the glaring differences between cases in each context, not much could be said in regards to the effects of the various depositional contexts on the rate of decay utilizing this particular analytical method. However, an additional method was developed which utilized the formulas developed in the regression analyses applied to the non-water outdoor and indoor subsets, and produced a set of predicted ADDs per each total body score possible. Based on the comparison of the predicted accumulated degree days, one can theoretically determine which context displays the slowest or fastest time to produce each decompositional stage.

Contrary to what was observed in the previous analysis, this particular method produced results much more in-line with what one would expect. Although in the early stages of decomposition, the rate of decay was slower in outdoor cases and fastest in indoor cases, passed a total body score of 11, non-water outdoor cases were shown to decompose the fastest (see Table 26). The joint non-water outdoor and indoor model produced results in-line with what one would expect, demonstrating a rate of decay in between that of outdoor and indoor cases.

Table 26. Predicted ADD Values per TBS using each Stratified Formula

Total Body Score	Outdoor	Indoor	Outdoor and Indoor
3	49.11339996	37.53185	51.72494053
4	55.70574669	44.0352	58.80306995
5	63.18296467	51.66542	66.84978272
6	71.66382755	60.61778	75.99762144
7	81.28305162	71.12135	86.39726607
8	92.19343575	83.44494	98.22001588
9	104.5682885	97.9039	111.660611
10	118.6041813	114.8682	126.9404402
11	134.5240705	134.7721	144.3111874
12	152.5808395	158.1248	164.0589773
13	173.0613153	185.524	186.5090887
14	196.2908248	217.6707	212.0313117
15	222.638363	255.3877	241.0460394
16	252.5224533	299.6401	274.0311921
17	286.417797	351.5604	311.5300896
18	324.8628126	412.4772	354.1604004
19	368.4681891	483.9494	402.624316
20	417.9265867	567.806	457.7201167
21	474.023639	666.1929	520.3553211
22	537.6504331	781.6278	591.5616342
23	609.817664	917.0647	672.511941
24	691.6716893	1075.97	764.5396264

25	784.5127388	1262.409	869.1605379
26	889.8155684	1481.153	988.0979539
27	1009.252886	1737.801	1123.31097
28	1144.721922	2038.919	1277.026766
29	1298.374568	2392.214	1451.777295
30	1472.651554	2806.726	1650.440986
31	1670.321226	3293.063	1876.290156
32	1894.523514	3863.67	2133.044913
33	2148.819814	4533.149	2424.934431
34	2437.249556	5318.633	2756.76661
35	2764.394371	6240.221	3134.007273
36	3135.450869	7321.499	3562.870194
37	3556.313186	8590.135	4050.419451
38	4033.666609	10078.6	4604.685784
39	4575.093773	11824.97	5234.79887
40	5189.195108	13873.95	5951.13771
41	5885.725453	16277.96	6765.501583
42	6675.74901	19098.53	7691.304403

Upon comparison of the results observed between the non-water outdoor and indoor formulas, a statistically significant difference was determined (see Tables 27 and 28). Therefore, one can conclude that these particular results are indicative of the rate of decay in each depositional context, fastest in outdoor cases and slowest in indoor environments.

Table 27. Predicted ADD Values per TBS using Indoor vs. Outdoor Formulas: Two Sample t-Test Assuming Unequal Variance

t-Test: Two-Sample Assuming Unequal Variances: Indoor vs Outdoor		
	Indoor	***Outdoor***
Mean	3227.563778	1401.115083
Variance	23504398.16	3117946.994
Observations	40	40
Hypothesized Mean Difference	0	
df	49	
t Stat	2.238794949	
P(T<=t) one-tail	0.014871835	
t Critical one-tail	1.676550893	
P(T<=t) two-tail	0.02974367	
t Critical two-tail	2.009575237	

Table 28. Predicted ADD Values per TBS using Indoor vs. Non-Water Outdoor and Indoor Formulas: Two Sample t-Test Assuming Unequal Variance

t-Test: Two-Sample Assuming Unequal Variances: Indoor vs Non-Water Outdoor and Indoor		
	Indoor	***Outdoor and Indoor***
Mean	3227.563778	1587.979022
Variance	23504398.16	4117592.255

Observations	40	40
Hypothesized Mean Difference	0	
Df	52	
t Stat	1.973042237	
P(T<=t) one-tail	0.02690859	
t Critical one-tail	1.674689154	
P(T<=t) two-tail	0.05381718	
t Critical two-tail	2.006646805	

Delaware River Valley Model versus Megyesi et al. (2005) Model

Lastly, a comparison was made between the Megyesi et al. (2005) model and both the overall and non-water outdoor and indoor Delaware River Valley models. This was done in an attempt to assess which model is more applicable to the area and more accurate in determining time since death.

In order to do so, two different analyses were utilized. The first applied the Megyesi et al. (2005) model to the subset and overall data gathered in this study. Based on a comparison of the R^2 values, the Delaware River Valley models explained a larger proportion of the variation in decomposition, regardless of if all cases or just the non-water outdoor and indoor cases were utilized. Figures 9 and 17, in comparison to Figures 30 and 31, demonstrate this difference.

Figure 30. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data Plot and Regression Equation

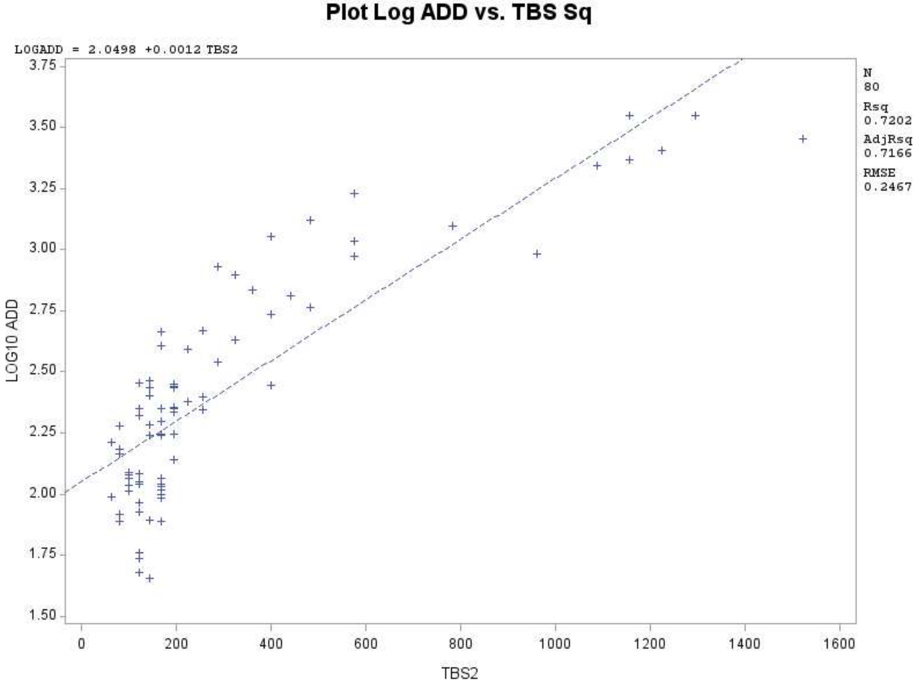
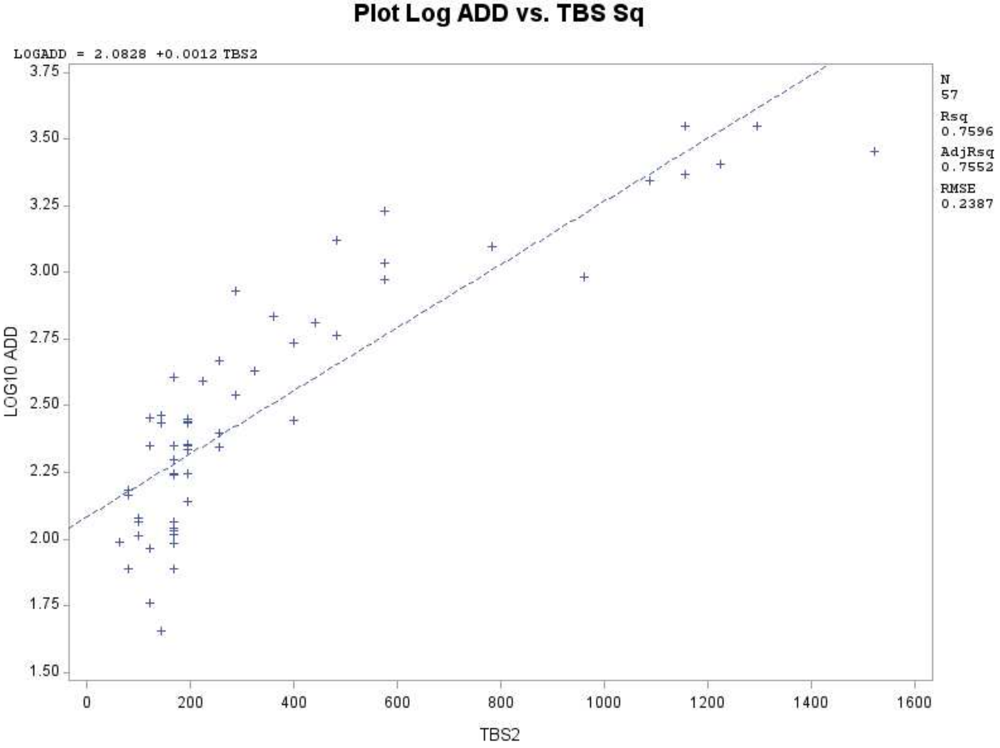


Figure 31. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data Plot and Regression Equation



The second method applied each regression equation developed from both studies to the actual total body scores determined in each case, producing a set of predicted ADD values. In turn, these were compared to the actual ADD values observed in each case. Specifically, the average ADD, average differential, and average absolute value differential between predicted and actual values, were compared. Across each and every comparision, utilizing all cases, as well as the non-water outdoor and indoor subset, the Delaware River Valley model was more accurate in estimating accumulated degree days (see Tables 29 through 34). Although these differences were not deemed statistically significant, with a larger sample size, statistical significance is likely to be achieved (see Tables 35 through 40).

Table 29. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data: Actual vs. Predicted ADD Values

Case #	Actual ADD	DRV Predicted ADD	Megyesi Predicted ADD
1	650.278	494.704	447.198
6	2555	3321.085	3104.56
11	174.722	184.765	140.605
15	116.111	184.765	140.605
21	103.333	124.603	102.329
34	347.5	312.421	244.343
35	276.111	210.693	159.221
42	146.111	109.27	93.756
66	226.944	210.693	159.221
69	391.667	240.259	181.97

29	96.389	184.765	140.605
36	285	142.089	112.72
37	152.5	109.27	93.756
44	97.778	95.823	86.696
45	175	210.693	159.221
47	138.333	210.693	159.221
48	224.722	142.089	112.72
49	77.222	109.27	93.756
50	405.833	184.765	140.605
51	217.222	210.693	159.221
52	271.389	210.693	159.221
53	110.278	184.765	140.605
55	683.611	406.256	340.408
56	292.778	162.028	125.314
57	107.222	184.765	140.605
58	198.056	184.765	140.605
60	464.722	273.974	209.894
61	92.222	142.089	112.72
62	278.889	463.266	407.38
63	271.667	162.028	125.314
64	427.778	356.262	287.078
65	176.389	184.765	140.605
68	282.5	210.693	159.221
69	391.667	240.259	181.97

71	103.611	184.765	140.605
72	116.111	124.603	102.329
73	57.222	142.089	112.72
74	250	273.974	209.894
76	1327.778	602.407	599.791
77	222.5	273.974	209.894
78	45.278	162.028	125.314
79	578.611	602.407	599.791
80	541.389	463.266	407.38
5	2333.056	2912.393	3104.56
9	1245.833	1324.555	1853.532
10	120	124.603	102.329
12	848.889	312.421	244.343
13	1079.444	783.339	916.22
14	2838.889	5615.65	7221.074
17	3532.778	2912.393	4073.803
18	2215.556	2553.994	4073.803
22	965.833	1964.084	3104.56
23	1690.833	783.339	916.22
26	223.333	184.765	140.605
27	223.333	210.693	159.221
28	941.667	783.339	916.22
29	96.389	184.765	140.605
81	239.05	580.9751894	292.0583847

83	191.8055556	328.3764995	169.6291924
84	191.8055556	328.3764995	169.6291924
86	162.2	153.4586521	99.18470562
88	462.5	397.1615906	200.5998292
89	789.5	1027.881627	567.3830241
90	120.9	271.5044153	145.3774435
91	251.6	328.3764995	169.6291924
92	78.21294444	328.3764995	169.6291924
93	82.57	185.6036667	111.1652591
94	47.90222222	271.5044153	145.3774435
96	146.0412222	185.6036667	111.1652591
97	173.3101667	328.3764995	169.6291924
98	109.8848889	271.5044153	145.3774435
99	84.10216667	271.5044153	145.3774435
101	1138.85	1367.212002	827.4538051
104	108.4026667	224.482104	126.2757211
105	208.9	271.5044153	145.3774435
110	122.7288889	224.482104	126.2757211
114	189.8	185.6036667	111.1652591
115	112.5	271.5044153	145.3774435
117	54.53327778	271.5044153	145.3774435
124	99	397.1615906	200.5998292
Average:	**470.8922069**	**528.8987658**	**535.2149608**

Standard Deviation:	**674.0655285**	**865.6399457**	**1131.718112**

Table 30. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data: Average Actual vs. Predicted ADD Value Differential

Case #	**DRV ADD Differential**	**Megyesi ADD Differential**
1	-155.574	-203.08
6	766.085	549.56
11	10.043	-34.117
15	68.654	24.494
21	21.27	-1.004
34	-35.079	-103.157
35	-65.418	-116.89
42	-36.841	-52.355
66	-16.251	-67.723
69	-151.408	-209.697
29	88.376	44.216
36	-142.911	-172.28
37	-43.23	-58.744
44	-1.955	-11.082
45	35.693	-15.779
47	72.36	20.888
48	-82.633	-112.002
49	32.048	16.534

50	-221.068	-265.228
51	-6.529	-58.001
52	-60.696	-112.168
53	74.487	30.327
55	-277.355	-343.203
56	-130.75	-167.464
57	77.543	33.383
58	-13.291	-57.451
60	-190.748	-254.828
61	49.867	20.498
62	184.377	128.491
63	-109.639	-146.353
64	-71.516	-140.7
65	8.376	-35.784
68	-71.807	-123.279
69	-151.408	-209.697
71	81.154	36.994
72	8.492	-13.782
73	84.867	55.498
74	23.974	-40.106
76	-725.371	-727.987
77	51.474	-12.606
78	116.75	80.036
79	23.796	21.18

80	-78.123	-134.009
5	579.337	771.504
9	78.722	607.699
10	4.603	-17.671
12	-536.468	-604.546
13	-296.105	-163.224
14	2776.761	4382.185
17	-620.385	541.025
18	338.438	1858.247
22	998.251	2138.727
23	-907.494	-774.613
26	-38.568	-82.728
27	-12.64	-64.112
28	-158.328	-25.447
29	88.376	44.216
81	341.9251894	53.00838473
83	136.5709439	-22.17636312
84	136.5709439	-22.17636312
86	-8.741347885	-63.01529438
88	-65.33840937	-261.9001708
89	238.3816274	-222.1169759
90	150.6044153	24.47744348
91	76.7764995	-81.97080756
92	250.1635551	91.416248

93	103.0336667	28.59525906
94	223.602193	97.47522126
96	39.56244452	-34.87596314
97	155.0663328	-3.680974259
98	161.6195264	35.49255458
99	187.4022486	61.27527681
101	228.3620017	-311.3961949
104	116.0794373	17.87305442
105	62.60441525	-63.52255652
110	101.7532151	3.546832222
114	-4.196333285	-78.63474094
115	159.0044153	32.87744348
117	216.9711375	90.8441657
124	298.1615906	101.5998292
Average:	**58.00655886**	**64.32275385**

Table 31. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data: Average Actual vs. Predicted ADD Absolute Value Differential

Case #	DRV Absolute Value Differential	Megyesi Absolute Value Differential
1	155.574	203.08
6	766.085	549.56
11	10.043	34.117
15	68.654	24.494

21	21.27	1.004
34	35.079	103.157
35	65.418	116.89
42	36.841	52.355
66	16.251	67.723
69	151.408	209.697
29	88.376	44.216
36	142.911	172.28
37	43.23	58.744
44	1.955	11.082
45	35.693	15.779
47	72.36	20.888
48	82.633	112.002
49	32.048	16.534
50	221.068	265.228
51	6.529	58.001
52	60.696	112.168
53	74.487	30.327
55	277.355	343.203
56	130.75	167.464
57	77.543	33.383
58	13.291	57.451
60	190.748	254.828
61	49.867	20.498

62	184.377	128.491
63	109.639	146.353
64	71.516	140.7
65	8.376	35.784
68	71.807	123.279
69	151.408	209.697
71	81.154	36.994
72	8.492	13.782
73	84.867	55.498
74	23.974	40.106
76	725.371	727.987
77	51.474	12.606
78	116.75	80.036
79	23.796	21.18
80	78.123	134.009
5	579.337	771.504
9	78.722	607.699
10	4.603	17.671
12	536.468	604.546
13	296.105	163.224
14	2776.761	4382.185
17	620.385	541.025
18	338.438	1858.247
22	998.251	2138.727

23	907.494	774.613
26	38.568	82.728
27	12.64	64.112
28	158.328	25.447
29	88.376	44.216
81	341.9251894	53.00838473
83	136.5709439	22.17636312
84	136.5709439	22.17636312
86	8.741347885	63.01529438
88	65.33840937	261.9001708
89	238.3816274	222.1169759
90	150.6044153	24.47744348
91	76.7764995	81.97080756
92	250.1635551	91.416248
93	103.0336667	28.59525906
94	223.602193	97.47522126
96	39.56244452	34.87596314
97	155.0663328	3.680974259
98	161.6195264	35.49255458
99	187.4022486	61.27527681
101	228.3620017	311.3961949
104	116.0794373	17.87305442
105	62.60441525	63.52255652
110	101.7532151	3.546832222

114	4.196333285	78.63474094
115	159.0044153	32.87744348
117	216.9711375	90.8441657
124	298.1615906	101.5998292
Average:	**195.2031861**	**236.781839**

Table 32. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data: Actual vs. Predicted ADD Values

Case	Actual ADD (Celsius)	DRV Predicted ADD	Megyesi Predicted ADD
1	650.278	488.033911	447.198
6	2555	3134.007273	3104.56
11	174.722	186.5090887	140.605
15	116.111	186.5090887	140.605
21	103.333	126.9404402	102.329
34	347.5	311.5300896	244.343
35	276.111	212.0313117	159.221
42	146.111	111.660611	93.756
66	226.944	212.0313117	159.221
69	391.667	241.0460394	181.97
29	96.389	186.5090887	140.605
36	285	144.3111874	112.72
37	152.5	111.660611	93.756
44	97.778	98.22001588	86.696

45	175	212.0313117	159.221
47	138.333	212.0313117	159.221
48	224.722	144.3111874	112.72
49	77.222	111.660611	93.756
50	405.833	186.5090887	140.605
51	217.222	212.0313117	159.221
52	271.389	212.0313117	159.221
53	110.278	186.5090887	140.605
55	683.611	402.624316	340.408
56	292.778	164.0589773	125.314
57	107.222	186.5090887	140.605
58	198.056	186.5090887	140.605
60	464.722	274.0311921	209.894
61	92.222	144.3111874	112.72
62	278.889	457.7201167	407.38
63	271.667	164.0589773	125.314
64	427.778	354.1604004	287.078
65	176.389	186.5090887	140.605
68	282.5	212.0313117	159.221
69	391.667	241.0460394	181.97
71	103.611	186.5090887	140.605
72	116.111	126.9404402	102.329
73	57.222	144.3111874	112.72
74	250	274.0311921	209.894

76	1327.778	591.5616342	599.791
77	222.5	274.0311921	209.894
78	45.278	164.0589773	125.314
79	578.611	591.5616342	599.791
80	541.389	457.7201167	407.38
5	2333.056	2756.76661	3104.56
9	1245.833	1277.026766	1853.532
10	120	126.9404402	102.329
12	848.889	311.5300896	244.343
13	1079.444	764.5396264	916.22
14	2838.889	5234.79887	7221.074
17	3532.778	2756.76661	4073.803
18	2215.556	2424.934431	4073.803
22	965.833	1876.290156	3104.56
23	1690.833	764.5396264	916.22
26	223.333	186.5090887	140.605
27	223.333	212.0313117	159.221
28	941.667	764.5396264	916.22
29	96.389	186.5090887	140.605
Average ADD	**570.2680175**	**572.9146119**	**669.7909123**
Std Dev	**761.9338975**	**941.9067828**	**1316.001524**

Table 33. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data: Average Actual vs. Predicted ADD Value Differential

Case	DRV Predicted Differential	Megyesi Predicted Differential
1	-162.244089	-203.08
6	579.0072731	549.56
11	11.78708866	-34.117
15	70.39808866	24.494
21	23.6074402	-1.004
34	-35.9699104	-103.157
35	-64.07968833	-116.89
42	-34.45038899	-52.355
66	-14.91268833	-67.723
69	-150.6209606	-209.697
29	90.12008866	44.216
36	-140.6888126	-172.28
37	-40.83938899	-58.744
44	0.442015877	-11.082
45	37.03131167	-15.779
47	73.69831167	20.888
48	-80.41081263	-112.002
49	34.43861101	16.534
50	-219.3239113	-265.228
51	-5.190688326	-58.001

52	-59.35768833	-112.168
53	76.23108866	30.327
55	-280.986684	-343.203
56	-128.7190227	-167.464
57	79.28708866	33.383
58	-11.54691134	-57.451
60	-190.6908079	-254.828
61	52.08918737	20.498
62	178.8311167	128.491
63	-107.6080227	-146.353
64	-73.61759957	-140.7
65	10.12008866	-35.784
68	-70.46868833	-123.279
69	-150.6209606	-209.697
71	82.89808866	36.994
72	10.8294402	-13.782
73	87.08918737	55.498
74	24.0311921	-40.106
76	-736.2163658	-727.987
77	51.5311921	-12.606
78	118.7809773	80.036
79	12.95063418	21.18
80	-83.66888329	-134.009
5	423.7106103	771.504

9	31.19376598	607.699
10	6.940440196	-17.671
12	-537.3589104	-604.546
13	-314.9043736	-163.224
14	2395.90987	4382.185
17	-776.0113897	541.025
18	209.378431	1858.247
22	910.4571558	2138.727
23	-926.2933736	-774.613
26	-36.82391134	-82.728
27	-11.30168833	-64.112
28	-177.1273736	-25.447
29	90.12008866	44.216
Average Differential	**2.646594367**	**99.52289474**
Std Dev	**422.1436409**	**736.5576306**

Table 34. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data: Average Actual vs. Predicted ADD Value Absolute Value Differential

Case	**DRV Absolute Value Differential**	**Megyesi Absolute Value Differential**
1	162.244089	203.08
6	579.0072731	549.56
11	11.78708866	34.117

15	70.39808866	24.494
21	23.6074402	1.004
34	35.9699104	103.157
35	64.07968833	116.89
42	34.45038899	52.355
66	14.91268833	67.723
69	150.6209606	209.697
29	90.12008866	44.216
36	140.6888126	172.28
37	40.83938899	58.744
44	0.442015877	11.082
45	37.03131167	15.779
47	73.69831167	20.888
48	80.41081263	112.002
49	34.43861101	16.534
50	219.3239113	265.228
51	5.190688326	58.001
52	59.35768833	112.168
53	76.23108866	30.327
55	280.986684	343.203
56	128.7190227	167.464
57	79.28708866	33.383
58	11.54691134	57.451
60	190.6908079	254.828

61	52.08918737	20.498
62	178.8311167	128.491
63	107.6080227	146.353
64	73.61759957	140.7
65	10.12008866	35.784
68	70.46868833	123.279
69	150.6209606	209.697
71	82.89808866	36.994
72	10.8294402	13.782
73	87.08918737	55.498
74	24.0311921	40.106
76	736.2163658	727.987
77	51.5311921	12.606
78	118.7809773	80.036
79	12.95063418	21.18
80	83.66888329	134.009
5	423.7106103	771.504
9	31.19376598	607.699
10	6.940440196	17.671
12	537.3589104	604.546
13	314.9043736	163.224
14	2395.90987	4382.185
17	776.0113897	541.025
18	209.378431	1858.247

22	910.4571558	2138.727
23	926.2933736	774.613
26	36.82391134	82.728
27	11.30168833	64.112
28	177.1273736	25.447
29	90.12008866	44.216
Average Abs. Val. Differential	**199.9116468**	**300.6771754**
Std Dev	**370.8558504**	**678.6587147**

Table 35. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data: Actual vs. Predicted ADD Values Two Sample t-Test Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances (All-M ADD vs DRV ADD)		
	M ADD	**DRV ADD**
Mean	535.2149608	528.8987658
Variance	1280785.886	749332.5156
Observations	80	80
Hypothesized Mean Difference	0	
df	148	
t Stat	0.039649694	
P(T<=t) one-tail	0.484212922	
t Critical one-tail	1.655214506	
P(T<=t) two-tail	0.968425844	

t Critical two-tail	1.976122494	

Table 36. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data: Average Actual vs. Predicted ADD Value Differential Two Sample t-Test Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances (All-M diff vs DRV diff)		
	M diff	**DRV diff**
Mean	64.32275385	58.00655886
Variance	391134.7549	161248.9273
Observations	80	80
Hypothesized Mean Difference	0	
df	135	
t Stat	0.07601164	
P(T<=t) one-tail	0.469761184	
t Critical one-tail	1.656219133	
P(T<=t) two-tail	0.939522367	
t Critical two-tail	1.977692277	

Table 37. Megyesi et al. (2005) ADD Model with Delaware River Valley Overall ADD Data: Average Actual vs. Predicted ADD Absolute Value Differential Two Sample t-Test Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances (All-M Ab Val vs DRV Ab Val)		
	M Ab Val	**DRV Ab Val**
Mean	236.781839	195.2031861
Variance	338549.2131	126069.6635

Observations	80	80
Hypothesized Mean Difference	0	
df	131	
t Stat	0.54559073	
P(T<=t) one-tail	0.293137558	
t Critical one-tail	1.656568649	
P(T<=t) two-tail	0.586275117	
t Critical two-tail	1.978238539	

Table 38. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data: Actual vs. Predicted ADD Values Two Sample t-Test Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances: Megyesi vs. DRV ADD		
	Megyesi	***DRV***
Mean	669.7909123	572.9146119
Variance	1731860.01	887188.3875
Observations	57	57
Hypothesized Mean Difference	0	
df	101	
t Stat	0.451942528	
P(T<=t) one-tail	0.326139736	
t Critical one-tail	1.66008063	
P(T<=t) two-tail	0.652279472	
t Critical two-tail	1.983731003	

Table 39. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data: Average Actual vs. Predicted ADD Value Differential Two Sample t-Test Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances: Megyesi vs. DRV ADD Differential		
	Megyesi	***DRV***
Mean	99.52289474	2.646594367
Variance	542517.1432	178205.2535
Observations	57	57
Hypothesized Mean Difference	0	
df	89	
t Stat	0.861531109	
P(T<=t) one-tail	0.195630424	
t Critical one-tail	1.662155326	
P(T<=t) two-tail	0.391260848	
t Critical two-tail	1.9869787	

Table 40. Megyesi et al. (2005) ADD Model with Delaware River Valley Non-Water Outdoor and Indoor ADD Data: Average Actual vs. Predicted ADD Value Absolute Value Differential Two Sample t-Test Assuming Unequal Variances

t-Test: Two-Sample Assuming Unequal Variances: Megyesi vs. DRV ADD Absolute Value Differential		
	Megyesi	***DRV***
Mean	300.6771754	199.9116468
Variance	460577.651	137534.0618
Observations	57	57
Hypothesized Mean Difference	0	

df	87	
t Stat	0.983690012	
P(T<=t) one-tail	0.163997856	
t Critical one-tail	1.662557349	
P(T<=t) two-tail	0.327995711	
t Critical two-tail	1.987608282	

Thus, in regards to estimating time since death in the Delaware River Valley, given the larger proportion of variation explained by the models developed in this study, as well as their greater precision and accuracy in estimating ADD, it is obvious why the regression equations derived from this research are favored over those from Megyesi et al. (2005). Not only did this study develop decompositional models better-suited to the area, but these results also validate the development of region-specific standards.

SAS Statistical Program Code

Lastly, in order to facilitate the development of future studies aimed at developing region-specific standards which employ similar methodology, and to provide greater transparency in regards to the statistical analyses utilized in this study, the SAS code used for each analysis is provided below. Given the assessment of accumulated degree days versus post-mortem interval days, the SAS code is divided by ADD and PMI (see Tables 41 and 42).

Table 41. Accumulated Degree Day SAS Code

```
/*** TITLE: ADD
**** DATA: SERGIOFINALDATA
**** AUTHOR: PAM PHOJANAKONG
**** DATE: 20-OCT-2013
```

```
20-Oct: Salinitynum and indoor_dirtnum created to account for format issues.
16-NOV: Added in soil pH to datasets and models.
20-Nov: Changed ADD to Celsius
2-Dec: Modified ADD Celsius and excluded outliers
2-Jan-14: Removed Ancestry and body weight per agreement on 19-Dec; additional
comparisons (T-tests);
                    Added in plots with TBS-squared.
13-Jan-14: Changed additional comparisons (T-tests) from ADD to rate=TBS/ADD
Apr-14: Surface Level only analyses
***/


LIBNAME sergio 'G:\CURRENT WORK\Sergio' ;

PROC IMPORT OUT= sergio.final
         DATAFILE= "G:\CURRENT WORK\Sergio\finaldata3pH.csv"
         DBMS=CSV REPLACE;
    GETNAMES=YES;
    DATAROW=2;
RUN;

PROC SQL ;
         DELETE
                  FROM sergio.final
                  WHERE id_code eq . ;


proc contents data=sergio.final varnum ;
run ;

PROC FORMAT ;
         VALUE town
                  1='Kent'
                  2='New Castle'
                  3='Sussex' ;
         VALUE sex
                  1='Male'
                  2='Female' ;
         VALUE body_position
                  1='Hanging'
                  2='Left side'
                  3='Prone'
                  4='Right side'
                  5='Seated'
                  6='Supine'
```

```
        .='Unknown' ;
    VALUE Insect
        0='Absent'
        1='Present'
        2='Present - Extensive'
        3='Artifact' ;
    VALUE Decomp
        0='Surface'
        1='Water' ;
    VALUE Salinity
        0='Freshwater = 0'
        1='Low = < 5'
        2='Low Medium = 5-10'
        3='Medium = 10-15'
        4='High Medium = 15-20'
        5='Low High = 20-25'
        6='High = 25-32'
        7='Open Water = >32'
        . ='n/a' ;
    VALUE Soil
        1='Loam'
        2='Sandy Loam'
        3='Silt Loam'
        4='Moderately decomposed plant material'
        .='Unavailable or n/a' ;
    VALUE pH
        99='n/a' ;
    VALUE YesNo
        0='No'
        1='Yes'
        . ='N/A' ;
RUN ;

DATA sergio.final ;
    SET sergio.final ;
    Salinitynum=salinity*1 ;
    Insect_total=Insects_Head_Neck + Insects_Torso + Insects_Limbs ;
    Trauma_total=Trauma_Head_Neck + Trauma_Torso + Trauma_Limbs ;
    Scav_total=Scav_Head + Scav_Torso + Scav_Limbs ;
    Indoor_dirtnum=1*Indoor_Dirty ;
    LABEL ID_Code='ID Code'
        Town='Town'
        Decomp_case='Decomposition Case'
        Indoor='Indoor'
        Outdoor='Outdoor'
```

```
    Soil_Type='Surface: Soil Type'
    Soil_pH='Soil pH'
    salinitynum='Water: Salinity'
    Surface_And_Water='Surface and Water'
    NonSurface_NonWater_Outdoor='Non-Surface/ Non-Water Outdoor'
    Outside_Sun='Outside: Sun'
    Outside_Shade='Outside: Shade'
    Surface_Indoor='Surface Indoor'
    Water_Indoor='Water Indoor'
    Indoor_Dirty='Indoor: Dirty'
    Indoor_dirtnum='Indoor: Dirty (number)'
    ADD_num='ADD score'
    ADD='ADD'
    Precip='Precipitation (Rain, Melted Snow in inches)'
    Sex='Sex'
    Age='Age'
    Ancestry='Ancestry'
    Height='Height (cm)'
    Weight='Weight (lbs)'
    Body_Position='Body Position'
    Head_Neck='TBS: Head/ Neck'
    Trunk='TBS: Trunk'
    Limbs='TBS: Limbs'
    TBS='TBS'
    Insects_Head_Neck='Insects: Head/Neck'
    Insects_Torso='Insects: Torso'
    Insects_Limbs='Insects: Limbs'
    Trauma_Head_Neck='Trauma: Head/Neck'
    Trauma_Torso='Trauma: Torso'
    Trauma_Limbs='Trauma: Limbs'
    Scav_head='Scavengers: Head/Neck'
    Scav_torso='Scavengers: Torso'
    Scav_Limbs='Scavengers: Limbs'
    Clothing_Head='Clothing:Head'
    Clothing_Torso_Arms='Clothing:Torso_Arms'
    Clothing_Hands_Feet='Clothing:Hands_Feet'
    Clothing_Legs='Clothing:Legs'
    Clothing_Total='Clothing Total'
    Insect_total='Total insect activity'
    Trauma_total='Total trauma to body'
    Scav_total='Total scavenger activity' ;
FORMAT town town.
        sex sex.
        body_position body_position.
        Insects_Head_Neck Insects_Torso Insects_Limbs Insect.
```

```
                              Decomp_case Decomp.
                              salinitynum Salinity.
                              Soil_type soil.
                              Soil_pH pH.
                              Indoor Outdoor Surface_and Water
NonSurface_NonWater_Outdoor Outside_Sun Outside_Shade Surface_Indoor
Water_Indoor Indoor_Dirtnum
                              Trauma_Head_Neck Trauma_Torso Trauma_Limbs YesNo. ;

RUN ;
/*** CHECK DATA FOR OUTLIERS ***/
proc univariate data=sergio.final ;
          var tbs add_num ;
          title 'CHECK FOR OUTLIERS' ;
run ;

data sergio.final_clean ;
          set sergio.final ;
          if 30 gt add_num then delete ;
          else if add_num gt 3600 then delete ;
run ;


/*** CHECK MODEL ASSUMPTIONS ***/
proc reg data=sergio.final_clean ;
          model ADD_num = TBS ;
          output out=pp p=pred r=resid lclm=lclmpred uclm=uclmpred ;
          title 'ADD and TBS - all' ;
run ;

proc capability data=pp ;
          var resid ;
          histogram resid/ normal ;
          probplot resid ;
          qqplot resid ;
run ;

proc reg data=sergio.final_clean ;
          model ADD_num = TBS ;
          plot student. *p. ;
run ;

/*** CHECK MODEL ASSUMPTIONS FOR LOG-TRANSFORMED DATA ***/
DATA SERGIO_ADD ;
          SET sergio.final_clean ;
```

```
          LOGADD=LOG10 (ADD_NUM) ;
          LABEL LOGADD='LOG10 ADD' ;
RUN;

PROC REG DATA=SERGIO_ADD ;
          MODEL LOGADD=TBS ;
          PLOT LOGADD*TBS ;
          TITLE 'Log ADD vs TBS' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*TBS=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs TBS' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Soil_pH ;
          TITLE 'Plot Log ADD vs. soil ph' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Salinity ;
          SYMBOL1 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Salinity' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Precip=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Precip' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Age=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Age' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Height=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
```

```
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Height' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*weight=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Weight' ;
RUN ;


PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Clothing_Total=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Clothing_Total' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Insect_total=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Insect_total ' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Trauma_total=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Trauma_total ' ;
RUN ;

PROC GPLOT DATA=SERGIO_ADD ;
          PLOT LOGADD*Scav_total=decomp_case ;
          SYMBOL1 V=circle C=black I=none;
          SYMBOL2 V=square   C=red   I=none;
          TITLE 'Plot Log ADD vs. Scav_total ' ;
RUN ;

/*** MODEL SELECION ***/
PROC GLMSELECT DATA=sergio_ADD ;
          CLASS Body_Position Ancestry Sex Decomp_case Outdoor ;
          MODEL LOGADD=Decomp_case Outdoor Precip Sex Age Height
Body_Position TBS Clothing_Total Insect_total
```

```
                    Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'MODEL SELECTION - ALL' ;
RUN ;

PROC REG DATA=sergio_ADD ;
        MODEL LOGADD=Precip TBS ;
        TITLE 'ADD (log) REGRESSION MODEL DIAGNOSTICS' ;
RUN ;


/*** SUBSET DATA BY SURFACE AND WATER ***/
DATA surface ;
        SET sergio_ADD ;
        WHERE decomp_case eq 0 ;
RUN ;

PROC REG DATA=surface ;
        MODEL LOGADD=TBS ;
        PLOT LOGADD*TBS ;
        TITLE 'Plot Log ADD vs. TBS - SURFACE' ;
RUN ;

DATA surface_indoor ;
        SET sergio_ADD ;
        WHERE decomp_case eq 0 AND indoor eq 1 ;
RUN ;

PROC REG DATA=surface_indoor ;
        MODEL LOGADD=TBS ;
        PLOT LOGADD*TBS ;
        TITLE 'Plot Log ADD vs. TBS - SURFACE(INDOOR)' ;
RUN ;

DATA surface_outdoor ;
        SET sergio_ADD ;
        WHERE decomp_case eq 0 AND outdoor eq 1 ;
RUN ;

PROC REG DATA=surface_outdoor ;
        MODEL LOGADD=TBS ;
        PLOT LOGADD*TBS ;
        TITLE 'Plot Log ADD vs. TBS - SURFACE(OUTDOOR)' ;
RUN ;
```

```
DATA water ;
        SET sergio_ADD ;
        WHERE decomp_case eq 1 ;
RUN ;

PROC REG DATA=water ;
        MODEL LOGADD=TBS ;
        PLOT LOGADD*TBS ;
        TITLE 'Plot Log ADD vs. TBS - WATER' ;
RUN ;

/*** MODEL SELECION: SUBSETS ***/
PROC GLMSELECT DATA=surface ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS Indoor_dirtnum Precip Sex Age Height Body_Position
Clothing_Total Insect_total
                        Trauma_total Scav_total /SELECTION=STEPWISE(SELECT=SL)
STATS=ALL ;
        TITLE 'ADD MODEL SELECTION - SURFACE' ;
RUN ;

PROC GLMSELECT DATA=surface_indoor ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS Indoor_dirtnum Precip Sex Age Height Body_Position
Clothing_Total Insect_total
                        Trauma_total Scav_total /SELECTION=STEPWISE(SELECT=SL)
STATS=ALL ;
        TITLE 'ADD MODEL SELECTION - SURFACE-INDOOR' ;
RUN ;

PROC GLMSELECT DATA=surface_outdoor ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS Soil_type Soil_pH Outside_sun Precip Sex Age Height
Body_Position Clothing_Total Insect_total
                        Trauma_total Scav_total /SELECTION=STEPWISE(SELECT=SL)
STATS=ALL ;
        TITLE 'ADD MODEL SELECTION - SURFACE-OUTDOOR' ;
RUN ;

PROC GLMSELECT DATA=water ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS salinitynum Outside_sun Water_indoor Precip Sex Age
Height Body_Position Clothing_Total Insect_total
                        Trauma_total Scav_total /SELECTION=STEPWISE(SELECT=SL)
STATS=ALL ;
```

```
        TITLE 'ADD MODEL SELECTION - WATER' ;
RUN ;

/*** SUBSET MODELS - USE ADJ R-SQUARED ***/

PROC GLMSELECT DATA=surface_indoor ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS Indoor_dirtnum Precip Sex Age Height Body_Position
Clothing_Total Insect_total
                 Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'ADD MODEL SELECTION - SURFACE-INDOOR' ;
RUN ;

PROC GLMSELECT DATA=surface_outdoor ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS Soil_type Soil_pH Outside_sun Sex Age Precip
Body_Position Clothing_Total Insect_total
        Trauma_total Scav_total /SELECTION=STEPWISE(SELECT=ADJRSQ)
STATS=ALL ;
        TITLE 'ADD MODEL SELECTION - SURFACE-OUTDOOR' ;
RUN ;

PROC GLMSELECT DATA=water ;
        CLASS Body_Position Sex ;
        MODEL LOGADD=TBS salinitynum Outside_sun Water_indoor Precip Sex Age
Height Body_Position Clothing_Total Insect_total
                 Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'ADD MODEL SELECTION - WATER' ;
RUN ;

/*Variables to Compare In Regards to their Influence of Decomposition and Decay Rate
1.      Dirty vs. Clean House
2.      Shaded vs. Exposed Remains
3.      Trauma vs. No Trauma
4.      Insect vs. No Insects
5.      Scavenging vs. No Scavenging
6.      Clothed vs. Not Clothed
7.      Soil pH Below 5.5 vs. Soil pH Above 5.5
a.      Arbitrary based on the pHs seen in the dataset
8.      Supine vs. Prone
9.      Supine vs. Seated
10.     Supine vs. Hanging
11.     Prone vs. Seated
```

```
12.     Prone vs. Hanging
13.     Seated vs. Hanging
14.     Water Salinity Medium and Below vs. Water Salinity High-Medium and Above
a.      Arbitrary to capture High vs. Low with Medium as Cut-Off
15.     Coastal vs. River
a.      I will have to compile a list of cases numbers belonging to each group
16.     Indoor vs. Outdoor (Surface)
17.     Indoor vs. Water
18.     Outdoor vs. Water
19.     Female vs. Male
20.     Below Age 50 vs. Above Age 50
a.      Arbitrary cut-off
21.     Below 6'0" vs. Above 6'0"
a.      Arbitrary cut-off
*/



/*CREATE NEW CATEGORIES FOR COMPARISONS*/
DATA sergio_ADD ;
        SET sergio_ADD ;
        if insect_total=0 then insect=0 ;
                else if insect_total gt 0 then insect=1 ;
        if trauma_total=0 then trauma=0 ;
                else if trauma_total gt 0 then trauma=1 ;
        if scav_total=0 then scav=0 ;
                else if scav_total gt 0 then scav=1 ;
        if soil_ph lt 5.5 then ph_score=0 ;
                else if soil_ph ge 5.5 then ph_score=1 ;
        if salinity le 3 then salinity_score=0 ;
                else if salinity gt 3 then salinity_score=1 ;
        if age lt 50 then age_score=0;
                else if age ge 50 then age_score=1 ;
        if height lt 72 then height_score=0 ;
                else if height ge 72 then height_score=1 ;
        if clothing_total=0 then clothing=0 ;
                else if clothing_total gt 0 then clothing=1 ;
        /*supine vs hanging*/
        if body_position=1 then hanging_sup=1 ;
                else if body_position=6 then hanging_sup=0;
                else hanging_sup=. ;
        /*supine vs. prone*/
        if body_position=3 then prone_s=1 ;
                else if body_position=6 then prone_s=0;
                else prone_s=. ;
```

```
        /*supine vs. seated*/
        if body_position=5 then seated_s=1 ;
                else if body_position=6 then seated_s=0;
                else seated_s=. ;
        /*prone vs seated*/
        if body_position=5 then seated_p=1 ;
                else if body_position=3 then seated_p=0;
                else seated_p=. ;
        /*prone vs hanging*/
        if body_position=1 then hanging_p=1 ;
                else if body_position=3 then hanging_p=0;
                else hanging_p=. ;
        /*seated vs hanging*/
        if body_position=1 then hanging_sit=1 ;
                else if body_position=5 then hanging_sit=0;
                else hanging_sit=. ;
        /*new decomp rate variable*/
        rate_add = tbs/add_num ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY indoor_dirty ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
        VAR rate_add ;
        CLASS indoor_dirty ;
        TITLE 'Dirty vs. Clean House' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY outside_shade ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
        VAR rate_add ;
        CLASS outside_shade ;
        TITLE 'Shaded vs. Exposed Remains' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY trauma ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
```

```
        VAR rate_add ;
        CLASS Trauma ;
        TITLE 'Trauma vs. No Trauma' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY insect ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
        VAR rate_add ;
        CLASS insect ;
        TITLE 'Insect vs. No Insects' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY clothing ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
        VAR rate_add ;
        CLASS clothing ;
        TITLE 'Clothed vs. Not Clothed' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY ph_score ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
        VAR rate_add ;
        CLASS ph_score ;
        TITLE 'Soil pH Below 5.5 vs. Soil pH Above 5.5' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
        BY scav ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
        VAR rate_add ;
        CLASS scav ;
        TITLE 'Scavenging vs. No Scavenging' ;
RUN ;
```

```
PROC SORT DATA=sergio_ADD ;
          BY prone_s ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS prone_s ;
          TITLE 'Supine (0) vs. Prone ' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY seated_s ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS seated_s ;
          TITLE 'Supine (0) vs. Seated ' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY hanging_sup ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS hanging_sup ;
          TITLE 'Supine (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY seated_p ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS seated_p ;
          TITLE 'Prone (0) vs. Seated ' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY hanging_p ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
```

```
          VAR rate_add ;
          CLASS hanging_p ;
          TITLE 'Prone (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY hanging_sit ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS hanging_sit ;
          TITLE 'Seated (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY salinity_score ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS salinity_score ;
          TITLE 'Water Salinity Medium and Below vs. Water Salinity High-Medium and
Above' ;
RUN ;

DATA sergio_ADD_surface ;
          SET sergio_ADD ;
          WHERE decomp_case=0 ;
RUN ;

PROC SORT DATA=sergio_ADD_surface ;
          BY indoor ;
RUN ;

PROC TTEST DATA=sergio_ADD_surface ;
          VAR rate_add ;
          CLASS indoor ;
          TITLE 'Indoor (0) vs. Outdoor (Surface)' ;
RUN ;

DATA sergio_ADD_indoor_water ;
          SET sergio_ADD ;
          IF indoor eq 0 and decomp_case eq 0 then DELETE ;
RUN ;
```

```
PROC SORT DATA=sergio_ADD_indoor_water ;
          BY decomp_case ;
RUN ;

PROC TTEST DATA=sergio_ADD_indoor_water ;
          VAR rate_add ;
          CLASS decomp_case ;
          TITLE 'Indoor vs ALL water' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY decomp_case ;
RUN ;

DATA sergio_ADD_outdoor_water ;
          SET sergio_ADD ;
          IF outdoor eq 0 and decomp_case eq 0 then DELETE ;
RUN ;

PROC SORT DATA=sergio_ADD_outdoor_water ;
          BY decomp_case ;
RUN ;

PROC TTEST DATA=sergio_ADD_outdoor_water ;
          VAR rate_add ;
          CLASS decomp_case ;
          TITLE 'Outdoor vs ALL water' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY decomp_case ;
RUN ;

PROC TTEST DATA=sergio_ADD_surface ;
          VAR rate_add ;
          CLASS indoor ;
          TITLE 'Indoor (0) vs. Outdoor (Surface)' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY sex ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
```

```
          VAR rate_add ;
          CLASS sex ;
          TITLE 'Female (2) vs. Male (1)' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY age_score ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS age_score ;
          TITLE 'Below Age 50 (0) vs. Above Age 50 (1)' ;
RUN ;

PROC SORT DATA=sergio_ADD ;
          BY height_score ;
RUN ;

PROC TTEST DATA=sergio_ADD ;
          VAR rate_add ;
          CLASS height_score ;
          TITLE 'Below 6'0" (0) vs. Above 6'0" (1)' ;
RUN ;

/*** T-TESTS with JUST SURFACE DATA ***/
/*CREATE NEW CATEGORIES FOR COMPARISONS*/
DATA surface_t ;
          SET surface ;
          if insect_total=0 then insect=0 ;
                    else if insect_total gt 0 then insect=1 ;
          if trauma_total=0 then trauma=0 ;
                    else if trauma_total gt 0 then trauma=1 ;
          if scav_total=0 then scav=0 ;
                    else if scav_total gt 0 then scav=1 ;
          if soil_ph lt 5.5 then ph_score=0 ;
                    else if soil_ph ge 5.5 then ph_score=1 ;
          if salinity le 3 then salinity_score=0 ;
                    else if salinity gt 3 then salinity_score=1 ;
          if age lt 50 then age_score=0;
                    else if age ge 50 then age_score=1 ;
          if height lt 72 then height_score=0 ;
                    else if height ge 72 then height_score=1 ;
          if clothing_total=0 then clothing=0 ;
                    else if clothing_total gt 0 then clothing=1 ;
```

```
        /*supine vs hanging*/
        if body_position=1 then hanging_sup=1 ;
                else if body_position=6 then hanging_sup=0;
                else hanging_sup=. ;
        /*supine vs. prone*/
        if body_position=3 then prone_s=1 ;
                else if body_position=6 then prone_s=0;
                else prone_s=. ;
        /*supine vs. seated*/
        if body_position=5 then seated_s=1 ;
                else if body_position=6 then seated_s=0;
                else seated_s=. ;
        /*prone vs seated*/
        if body_position=5 then seated_p=1 ;
                else if body_position=3 then seated_p=0;
                else seated_p=. ;
        /*prone vs hanging*/
        if body_position=1 then hanging_p=1 ;
                else if body_position=3 then hanging_p=0;
                else hanging_p=. ;
        /*seated vs hanging*/
        if body_position=1 then hanging_sit=1 ;
                else if body_position=5 then hanging_sit=0;
                else hanging_sit=. ;
        /*new decomp rate variable*/
        rate_add = tbs/add_num ;
RUN ;

PROC SORT DATA=surface_t ;
        BY indoor_dirty ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS indoor_dirty ;
        TITLE 'Dirty vs. Clean House' ;
RUN ;

PROC SORT DATA=surface_t ;
        BY outside_shade ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS outside_shade ;
```

```
          TITLE 'Shaded vs. Exposed Remains' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY trauma ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS Trauma ;
          TITLE 'Trauma vs. No Trauma' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY insect ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS insect ;
          TITLE 'Insect vs. No Insects' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY clothing ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS clothing ;
          TITLE 'Clothed vs. Not Clothed' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY ph_score ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS ph_score ;
          TITLE 'Soil pH Below 5.5 vs. Soil pH Above 5.5' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY scav ;
```

```
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS scav ;
        TITLE 'Scavenging vs. No Scavenging' ;
RUN ;

PROC SORT DATA=surface_t ;
        BY prone_s ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS prone_s ;
        TITLE 'Supine (0) vs. Prone ' ;
RUN ;

PROC SORT DATA=surface_t ;
        BY seated_s ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS seated_s ;
        TITLE 'Supine (0) vs. Seated ' ;
RUN ;

PROC SORT DATA=surface_t ;
        BY hanging_sup ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS hanging_sup ;
        TITLE 'Supine (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=surface_t ;
        BY seated_p ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS seated_p ;
```

```
          TITLE 'Prone (0) vs. Seated ' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY hanging_p ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS hanging_p ;
          TITLE 'Prone (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY hanging_sit ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS hanging_sit ;
          TITLE 'Seated (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY salinity_score ;
RUN ;

PROC SORT DATA=surface_t ;
          BY sex ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS sex ;
          TITLE 'Female (2) vs. Male (1)' ;
RUN ;

PROC SORT DATA=surface_t ;
          BY age_score ;
RUN ;

PROC TTEST DATA=surface_t ;
          VAR rate_add ;
          CLASS age_score ;
          TITLE 'Below Age 50 (0) vs. Above Age 50 (1)' ;
```

```
RUN ;

PROC SORT DATA=surface_t ;
        BY height_score ;
RUN ;

PROC TTEST DATA=surface_t ;
        VAR rate_add ;
        CLASS height_score ;
        TITLE 'Below 6’0” (0) vs. Above 6’0” (1)' ;
RUN ;

/*** TBS SQUARED PLOTS COMPARE TO MEGYESI - SURFACE ONLY ***/
DATA SERGIO_ADD_SURFACE;
        SET SERGIO_ADD ;
        IF decomp_case ne 0 THEN DELETE ;
        TBS2=TBS*TBS ;
RUN;

PROC REG DATA=SERGIO_ADD_SURFACE LINEPRINTER;
        MODEL LOGADD=TBS2 ;
        PAINT INDOOR=1 / symbol='*' ;
        PAINT INDOOR=0 /symbol='o' ;
        PLOT LOGADD*TBS2 ;
        TITLE 'Surface only - Log ADD vs. TBS Sq' ;
RUN ;


PROC REG DATA=SERGIO_ADD_SURFACE LINEPRINTER;
        MODEL LOGADD=TBS ;
        PAINT INDOOR=1 /symbol='*' ;
        PAINT INDOOR=0 /symbol='o' ;
        PLOT LOGADD*TBS / ;
        TITLE 'Surface only - Log ADD vs. TBS' ;
RUN ;


PROC GPLOT DATA=SERGIO_ADD_SURFACE ;
        WHERE decomp_case eq 0 ;
        PLOT LOGADD*TBS2=OUTDOOR ;
        SYMBOL1 V=Triangle C=black I=none ;
        SYMBOL2 V=star C=black I=none ;
        TITLE 'Surface only - Log ADD vs. TBS Sq' ;
RUN ;
```

```
PROC GPLOT DATA=SERGIO_ADD_SURFACE ;
        WHERE decomp_case eq 0 ;
        PLOT LOGADD*TBS=OUTDOOR ;
        SYMBOL1 V=Triangle C=black I=none ;
        SYMBOL2 V=star C=black I=none ;
        TITLE 'Surface only - Log ADD vs. TBS' ;
RUN ;
```

Table 42. Post-Mortem Interval Day SAS Code

```
/*** TITLE: PMI
**** DATA: SERGIOFINALDATA
**** AUTHOR: PAM PHOJANAKONG
**** DATE: 20-OCT-2013
20-Oct: Salinitynum and indoor_dirtnum created to account for format issues.
16-NOV: Added in soil pH to datasets and models.
2-Dec: look for outliers
2-Jan-14: Removed Ancestry and body weight per agreement on 19-Dec; additional
comparisons (T-tests);
                 Added in plots with TBS-squared.
13-Jan-14: Changed additional comparisons (T-tests) from PMI to rate=TBS/PMI
Apr-14: Added surface-only plots/analysis to compare to Megyesi et al
***/

LIBNAME sergio 'G:\CURRENT WORK\Sergio' ;

PROC IMPORT OUT= sergio.final
        DATAFILE= "F:\CURRENT WORK\Sergio\finaldata3pH.csv"
        DBMS=CSV REPLACE;
    GETNAMES=YES;
    DATAROW=2;
RUN;

PROC SQL ;
        DELETE
                FROM sergio.final
                WHERE id_code eq . ;


proc contents data=sergio.final varnum ;
run ;

PROC FORMAT ;
        VALUE town
                1='Kent'
                2='New Castle'
```

```
          3='Sussex' ;
     VALUE sex
          1='Male'
          2='Female' ;
     VALUE body_position
          1='Hanging'
          2='Left side'
          3='Prone'
          4='Right side'
          5='Seated'
          6='Supine'
          .='Unknown' ;
     VALUE Insect
          0='Absent'
          1='Present'
          2='Present - Extensive'
          3='Artifact' ;
     VALUE Decomp
          0='Surface'
          1='Water' ;
     VALUE Salinity
          0='Freshwater = 0'
          1='Low = < 5'
          2='Low Medium = 5-10'
          3='Medium = 10-15'
          4='High Medium = 15-20'
          5='Low High = 20-25'
          6='High = 25-32'
          7='Open Water = >32'
          . ='n/a' ;
     VALUE Soil
          1='Loam'
          2='Sandy Loam'
          3='Silt Loam'
          4='Moderately decomposed plant material'
          .='Unavailable or n/a' ;
     VALUE pH
          99='n/a' ;
     VALUE YesNo
          1='Yes'
          0='No'
          . ='N/A' ;
RUN ;

DATA sergio.final ;
```

```
SET sergio.final ;
Salinitynum=salinity*1 ;
Insect_total=Insects_Head_Neck + Insects_Torso + Insects_Limbs ;
Trauma_total=Trauma_Head_Neck + Trauma_Torso + Trauma_Limbs ;
Scav_total=Scav_Head + Scav_Torso + Scav_Limbs ;
Indoor_dirtnum=1*Indoor_Dirty ;
LABEL ID_Code='ID Code'
        Town='Town'
        Decomp_case='Decomposition Case'
        Indoor='Indoor'
        Outdoor'Outdoor'
        Soil_Type='Surface: Soil Type'
        Soil_pH='Soil pH'
        salinitynum='Water: Salinity'
        Surface_And_Water='Surface and Water'
        NonSurface_NonWater_Outdoor='Non-Surface/ Non-Water Outdoor'
        Outside_Sun='Outside: Sun'
        Outside_Shade='Outside: Shade'
        Surface_Indoor='Surface Indoor'
        Water_Indoor='Water Indoor'
        Indoor_Dirty='Indoor: Dirty'
        Indoor_dirtnum='Indoor: Dirty (number)'
        ADD_num='ADD score'
        ADD='ADD'
        Precip='Precipitation (Rain, Melted Snow, in inches)'
        Sex='Sex'
        Age='Age'
        Ancestry='Ancestry'
        Height='Height (cm)'
        Weight='Weight (lbs)'
        Body_Position='Body Position'
        Head_Neck='TBS: Head/ Neck'
        Trunk='TBS: Trunk'
        Limbs='TBS: Limbs'
        TBS='TBS'
        Insects_Head_Neck='Insects: Head/Neck'
        Insects_Torso='Insects: Torso'
        Insects_Limbs='Insects: Limbs'
        Trauma_Head_Neck='Trauma: Head/Neck'
        Trauma_Torso='Trauma: Torso'
        Trauma_Limbs='Trauma: Limbs'
        Scav_head='Scavengers: Head/Neck'
        Scav_torso='Scavengers: Torso'
        Scav_Limbs='Scavengers: Limbs'
        Clothing_Head='Clothing:Head'
```

```
                    Clothing_Torso_Arms='Clothing:Torso_Arms'
                    Clothing_Hands_Feet='Clothing:Hands_Feet'
                    Clothing_Legs='Clothing:Legs'
                    Clothing_Total='Clothing Total'
                    Insect_total='Total insect activity'
                    Trauma_total='Total trauma to body'
                    Scav_total='Total scavenger activity' ;
        FORMAT town town.
                        sex sex.
                        body_position body_position.
                        Insects_Head_Neck Insects_Torso Insects_Limbs Insect.
                        Decomp_case Decomp.
                        salinitynum Salinity.
                        Soil_type soil.
                        Soil_pH pH.
                        Indoor Outdoor Surface_and Water
NonSurface_NonWater_Outdoor Outside_Sun Outside_Shade Surface_Indoor
Water_Indoor Indoor_Dirtnum
                        Trauma_Head_Neck Trauma_Torso Trauma_Limbs YesNo. ;

RUN ;

/*** CHECK DATA FOR OUTLIERS ***/
proc univariate data=sergio.final ;
        var tbs pmi ;
        title 'CHECK FOR OUTLIERS' ;
run ;

/*** CHECK MODEL ASSUMPTIONS ***/
proc reg data=sergio.final_clean_pmi ;
        model PMI = TBS ;
        output out=pp p=pred r=resid lclm=lclmpred uclm=uclmpred ;
        title 'PMI and TBS - all' ;
run ;

proc capability data=pp ;
        var resid ;
        histogram resid/ normal ;
        probplot resid ;
        qqplot resid ;
run ;

proc reg data=sergio.final_clean_pmi ;
        model PMI = TBS ;
        plot student. *p. ;
```

```
run ;


/**       RAW PLOTS**/

proc reg data=sergio.final_clean_pmi ;
          model PMI = TBS ;
          PLOT PMI*TBS ;
          title 'PLOT PMI VS.TBS - all' ;
run ;


/*** CHECK MODEL ASSUMPTIONS FOR LOG-TRANSFORMED DATA ***/
DATA SERGIO_PMI ;
          SET sergio.final_clean_pmi ;
          LOGPMI=LOG10(PMI) ;
          LABEL LOGPMI='LOG10 PMI' ;
RUN;

PROC REG DATA=SERGIO_PMI ;
          MODEL LOGPMI=TBS ;
          PLOT LOGPMI*TBS ;
          TITLE 'Plot Log PMI vs. TBS - ALL' ;
RUN ;

/*** MODEL SELECION ***/
PROC GLMSELECT DATA=sergio_PMI ;
          CLASS Body_Position Sex Decomp_case Outdoor ;
          MODEL LOGPMI=Decomp_case Outdoor Precip Sex Age Height
Body_Position TBS Clothing_Total Insect_total
                     Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
          TITLE 'MODEL SELECTION - ALL' ;
RUN ;


/*** CHECK NOMALITY FOR SELECTED MODEL COVARIATES (SCAVENGERS
OUTDOOR) ***/

PROC REG DATA=sergio_PMI ;
          MODEL LOGPMI=Outdoor Precip Sex TBS Scav_total ;
          TITLE 'PMI (log) REGRESSION MODEL' ;
RUN ;

PROC REG DATA=sergio_PMI ;
```

```
        MODEL LOGPMI=Decomp_case Outdoor Precip Sex Height Body_Position
TBS Clothing_Total ;
        TITLE 'PMI (log) REGRESSION MODEL DIAGNOSTICS' ;
RUN ;

/*** SUBSET DATA BY SURFACE AND WATER ***/
DATA surface ;
        SET sergio_PMI ;
        WHERE decomp_case eq 0 ;
RUN ;

PROC REG DATA=surface ;
        MODEL LOGPMI=TBS ;
        PLOT LOGPMI*TBS ;
        TITLE 'Plot Log PMI vs. TBS - SURFACE' ;
RUN ;

DATA surface_indoor ;
        SET sergio_PMI ;
        WHERE decomp_case eq 0 AND indoor eq 1 ;
RUN ;

PROC REG DATA=surface_indoor ;
        MODEL LOGPMI=TBS ;
        PLOT LOGPMI*TBS ;
        TITLE 'Plot Log PMI vs. TBS - SURFACE(INDOOR)' ;
RUN ;

DATA surface_outdoor ;
        SET sergio_PMI ;
        WHERE decomp_case eq 0 AND outdoor eq 1 ;
RUN ;

PROC REG DATA=surface_outdoor ;
        MODEL LOGPMI=TBS ;
        PLOT LOGPMI*TBS ;
        TITLE 'Plot Log PMI vs. TBS - SURFACE(OUTDOOR)' ;
RUN ;

DATA water ;
        SET sergio_PMI ;
        WHERE decomp_case eq 1 ;
RUN ;

PROC REG DATA=water ;
```

```
        MODEL LOGPMI=TBS ;
        PLOT LOGPMI*TBS ;
        TITLE 'Plot Log PMI vs. TBS - WATER' ;
RUN ;

/*** MODEL SELECION: SUBSETS ***/
PROC GLMSELECT DATA=surface ;
        CLASS Body_Position Sex ;
        MODEL LOGPMI=TBS Indoor_dirtnum Precip Sex Age Height Body_Position
Clothing_Total Insect_total
                Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'PMI MODEL SELECTION - SURFACE' ;
RUN ;

PROC GLMSELECT DATA=surface_indoor ;
        CLASS Body_Position Sex ;
        MODEL LOGPMI=Indoor_dirtnum Precip Sex Age Height Body_Position TBS
Clothing_Total Insect_total
                Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'PMI MODEL SELECTION - SURFACE-INDOOR' ;
RUN ;

PROC GLMSELECT DATA=surface_outdoor ;
        CLASS Body_Position Sex ;
        MODEL LOGPMI=Soil_type Soil_pH Outside_sun Precip Sex Age Height
Body_Position TBS Clothing_Total Insect_total
                Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'PMI MODEL SELECTION - SURFACE-OUTDOOR' ;
RUN ;

PROC GLMSELECT DATA=water ;
        CLASS Body_Position Sex ;
        MODEL LOGPMI=Salinitynum Outside_sun Water_indoor Precip Sex Age
Height Body_Position TBS Clothing_Total Insect_total
                Trauma_total Scav_total
/SELECTION=STEPWISE(SELECT=ADJRSQ) STATS=ALL ;
        TITLE 'PMI MODEL SELECTION - WATER' ;
RUN ;

/*Variables to Compare In Regards to their Influence of Decomposition and Decay Rate
1.      Dirty vs. Clean House
2.      Shaded vs. Exposed Remains
```

```
3.      Trauma vs. No Trauma
4.      Insect vs. No Insects
5.      Scavenging vs. No Scavenging
6.      Clothed vs. Not Clothed
7.      Soil pH Below 5.5 vs. Soil pH Above 5.5
a.      Arbitrary based on the pHs seen in the dataset
8.      Supine vs. Prone
9.      Supine vs. Seated
10.     Supine vs. Hanging
11.     Prone vs. Seated
12.     Prone vs. Hanging
13.     Seated vs. Hanging
14.     Water Salinity Medium and Below vs. Water Salinity High-Medium and Above
a.      Arbitrary to capture High vs. Low with Medium as Cut-Off
15.     Coastal vs. River
a.      I will have to compile a list of cases numbers belonging to each group
16.     Indoor vs. Outdoor (Surface)
17.     Indoor vs. Water
18.     Outdoor vs. Water
19.     Female vs. Male
20.     Below Age 50 vs. Above Age 50
a.      Arbitrary cut-off
21.     Below 6’0” vs. Above 6’0”
a.      Arbitrary cut-off
*/


/*CREATE NEW CATEGORIES FOR COMPARISONS*/
DATA sergio_PMI ;
        SET sergio_PMI ;
        if insect_total=0 then insect=0 ;
                else if insect_total gt 0 then insect=1 ;
        if trauma_total=0 then trauma=0 ;
                else if trauma_total gt 0 then trauma=1 ;
        if scav_total=0 then scav=0 ;
                else if scav_total gt 0 then scav=1 ;
        if soil_ph lt 5.5 then ph_score=0 ;
                else if soil_ph ge 5.5 then ph_score=1 ;
        if salinity le 3 then salinity_score=0 ;
                else if salinity gt 3 then salinity_score=1 ;
        if age lt 50 then age_score=0;
                else if age ge 50 then age_score=1 ;
        if height lt 72 then height_score=0 ;
                else if height ge 72 then height_score=1 ;
        if clothing_total=0 then clothing=0 ;
```

```
            else if clothing_total gt 0 then clothing=1 ;
        /*supine vs hanging*/
        if body_position=1 then hanging_sup=1 ;
            else if body_position=6 then hanging_sup=0;
            else hanging_sup=. ;
        /*supine vs. prone*/
        if body_position=3 then prone_s=1 ;
            else if body_position=6 then prone_s=0;
            else prone_s=. ;
        /*supine vs. seated*/
        if body_position=5 then seated_s=1 ;
            else if body_position=6 then seated_s=0;
            else seated_s=. ;
        /*prone vs seated*/
        if body_position=5 then seated_p=1 ;
            else if body_position=3 then seated_p=0;
            else seated_p=. ;
        /*prone vs hanging*/
        if body_position=1 then hanging_p=1 ;
            else if body_position=3 then hanging_p=0;
            else hanging_p=. ;
        /*seated vs hanging*/
        if body_position=1 then hanging_sit=1 ;
            else if body_position=5 then hanging_sit=0;
            else hanging_sit=. ;
        /*new decomp rate variable*/
        rate_pmi = tbs/pmi ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY indoor_dirty ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS indoor_dirty ;
        TITLE 'Dirty vs. Clean House' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY outside_shade ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
```

```
          CLASS outside_shade ;
          TITLE 'Shaded vs. Exposed Remains' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
          BY trauma ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
          VAR rate_pmi ;
          CLASS Trauma ;
          TITLE 'Trauma vs. No Trauma' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
          BY insect ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
          VAR rate_pmi ;
          CLASS insect ;
          TITLE 'Insect vs. No Insects' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
          BY clothing ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
          VAR rate_pmi ;
          CLASS clothing ;
          TITLE 'Clothed vs. Not Clothed' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
          BY ph_score ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
          VAR rate_pmi ;
          CLASS ph_score ;
          TITLE 'Soil pH Below 5.5 vs. Soil pH Above 5.5' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
```

```
        BY scav ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS scav ;
        TITLE 'Scavenging vs. No Scavenging' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY prone_s ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS prone_s ;
        TITLE 'Supine (0) vs. Prone ' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY seated_s ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS seated_s ;
        TITLE 'Supine (0) vs. Seated ' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY hanging_sup ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS hanging_sup ;
        TITLE 'Supine (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY seated_p ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
```

```
        CLASS seated_p ;
        TITLE 'Prone (0) vs. Seated ' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY hanging_p ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS hanging_p ;
        TITLE 'Prone (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY hanging_sit ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS hanging_sit ;
        TITLE 'Seated (0) vs. Hanging' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY salinity_score ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS salinity_score ;
        TITLE 'Water Salinity Medium and Below vs. Water Salinity High-Medium and
Above' ;
RUN ;

DATA sergio_PMI_indoor_water ;
        SET sergio_PMI ;
        IF indoor eq 0 and decomp_case eq 0 then DELETE ;
RUN ;

PROC SORT DATA=sergio_PMI_indoor_water ;
        BY decomp_case ;
RUN ;

PROC TTEST DATA=sergio_PMI_indoor_water ;
```

```
        VAR rate_pmi ;
        CLASS decomp_case ;
        TITLE 'Indoor vs ALL water' ;
RUN ;

DATA sergio_PMI_outdoor_water ;
        SET sergio_PMI ;
        IF outdoor eq 0 and decomp_case eq 0 then DELETE ;
RUN ;

PROC SORT DATA=sergio_PMI_outdoor_water ;
        BY decomp_case ;
RUN ;

PROC TTEST DATA=sergio_PMI_outdoor_water ;
        VAR rate_pmi ;
        CLASS decomp_case ;
        TITLE 'Outdoor vs ALL water' ;
RUN ;

DATA sergio_PMI_surface ;
        SET sergio_PMI ;
        WHERE decomp_case=0 ;
RUN ;

PROC SORT DATA=sergio_PMI_surface ;
        BY indoor ;
RUN ;

PROC TTEST DATA=sergio_PMI_surface ;
        VAR rate_pmi ;
        CLASS indoor ;
        TITLE 'Indoor (0) vs. Outdoor (Surface)' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
        BY sex ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
        VAR rate_pmi ;
        CLASS sex ;
        TITLE 'Female (2) vs. Male (1)' ;
RUN ;
```

```
PROC SORT DATA=sergio_PMI ;
          BY age_score ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
          VAR rate_pmi ;
          CLASS age_score ;
          TITLE 'Below Age 50 (0) vs. Above Age 50 (1)' ;
RUN ;

PROC SORT DATA=sergio_PMI ;
          BY height_score ;
RUN ;

PROC TTEST DATA=sergio_PMI ;
          VAR rate_pmi ;
          CLASS height_score ;
          TITLE 'Below 6’0” (0) vs. Above 6’0” (1)' ;
RUN ;

/*** TBS SQUARED PLOTS COMPARE TO MEGYESI - SURFACE ONLY ***/
DATA SERGIO_PMI ;
          SET SERGIO_PMI ;
          TBS2=TBS*TBS ;
RUN;

PROC REG DATA=SERGIO_PMI ;
          WHERE decomp_case eq 0 ;
          MODEL LOGPMI=TBS2 ;
          PLOT LOGPMI*TBS2 ;
          TITLE 'Plot Log PMI vs. TBS Sq' ;

RUN ;PROC REG DATA=SERGIO_PMI ;
          WHERE decomp_case eq 0 ;
          MODEL LOGPMI=TBS ;
          PLOT LOGPMI*TBS ;
          TITLE 'Plot Log PMI vs. TBS' ;
RUN ;

PROC GPLOT DATA=SERGIO_PMI ;
          WHERE decomp_case eq 0 ;
          PLOT LOGPMI*TBS2=OUTDOOR ;
          SYMBOL1 V=Triangle C=black I=none ;
          SYMBOL2 V=star C=black I=none ;
          TITLE 'Surface only - Log PMI vs. TBS Sq' ;
```

```
RUN ;

PROC GPLOT DATA=SERGIO_PMI;
	WHERE decomp_case eq 0 ;
	PLOT LOGPMI*TBS=OUTDOOR ;
	SYMBOL1 V=Triangle C=black I=none ;
	SYMBOL2 V=star C=black I=none ;
	TITLE 'Surface only - Log PMI vs. TBS' ;
RUN ;
```

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