Human Decomposition and the Factors that Affect it: A Retrospective Study of Death Scenes in Canada

by

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Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

in the
Department of Archaeology
Faculty of Environment

SIMON FRASER UNIVERSITY

Spring 2013

Approval

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Degree: **Doctor of Philosophy Forensic Anthropology**

Title of Thesis: ***Human Decomposition and the Factors that Affect it: A Retrospective Study of Death Scenes in Canada***

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Abstract

Little is known about human decomposition and the variables which affect it in Canada. This study involves the retrospective analysis of 358 police death investigations from across Canada. Cases with reliable data were selected using the Canadian ViCLAS (Violent Crime Linkage Analysis System) database. A total of 36 environmental, immediate context, intrinsic and geographic variables were examined for each case. A classification system was designed based on biological processes of decomposition and a method developed to assign a relative value to each case (Relative Level of Decomposition Value). There are four components to the study. The first component determined the quantitative and qualitative differences in the progression of baseline decomposition for outdoor surface, buried, indoor and water scenes. The frequency of alternate states of decomposition such as mummification, adipocere formation or moulding was determined for each scene type. The second component determined which variables affected the progression of decomposition by scene type. The PMI (in days) was found to have more predictive value compared to the ADD score. Seven variables (PMI days, precipitation, scavenging, insects, body size, alcohol consumption and blood loss) were found to contribute to 83% of the variability in the decomposition score outside on the surface. Three variables (ADD score, insects and blood loss) indoors and in burials (PMI days, blood loss and clothing) contributed to 50% of the change in decomposition. Two variables (PMI days and submersion) contributed to 54% of the variability in decomposition in water. Insects and scavengers had a limited involvement in all cases regardless of season. The third component of the study found that there were geographical differences in baseline and alternate states of decomposition across Canada. The last component of the study tested existing formulas for PMI estimations using Canadian cases, with negative results. The variability within baseline decomposition, between scene types and geographical locations precludes the estimations of accurate or forensically practical PMI estimations in Canada. The understanding of decomposition could be used to determine the original context of found remains and predict the extent and type of decomposition given a set of known variables, for search and recovery strategies.

Keywords: Forensic taphonomy; human decomposition; PMI estimation; outdoor decomposition; indoor decomposition; variables affecting decomposition.

For David,

for all your,

Love and Support.

Acknowledgements

I would like to acknowledge the Royal Canadian Mounted Police as an organization for its support, encouragement and practical help throughout this project. Specifically I would like to thank Meilssa Martineau, ViCLAS research assistant at the Behavioural Sciences Branch, for her assistance with the acquisition of the data from ViCLAS. I would like to also thank Inspector Leo O'Brien the officer in charge (OIC) of ViCLAS, Behavioural Sciences Branch for approving my request to access the database. I would like to thank Deputy Commissioner B. Busson and Assistant Commissioner B. Corrigan for granting me access to the police files. I would like to thank Cathy Triveri, at 'E' Division Headquarters in Vancouver, and Liana Wadsworth and Jackie Turnbull at the 'HQ" Archives Branch in Ottawa for their assistance with search for and recovery of these investigational files which made this study possible.

The assistance that the Forensic Identification Members of the RCMP provided me by sending me photographs and files for some of their cases was invaluable. I also would like to thank the Forensic Identification members and students at the Canadian Police College and the Forensic Identification Operations Support Services (FIOSS) in Ottawa for their participation in the inter-observer error study.

I would like to gratefully acknowledge the assistance of the Ottawa Police Service by allowing me to access their death investigation files and photograph database. I would like to thank S/Sgt. Dwayne Raymond the OIC of the Forensic Unit for allowing me access and specifically to Sgt. Pam Scharf for her assistance with the search of the various police databases. I appreciate the assistance of Ofer Amram with the maps.

But most of all I like to thank my supervisor Dr. Lynne Bell, my mentor and friend for her insight, encouragement and enduring patience throughout this process, and David Thompson my husband for his unwavering faith that I would see this to a successful conclusion.

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1. Introduction

In 1977, after the profound embarrassment of underestimating the post mortem interval (PMI) of Colonel Shy by 112 years, William Bass realized that very little was known about human decomposition and the factors which affect it. This realization was the impetuous for the formation of the Anthropology Research Facility (ARF), otherwise known as the “Body Farm” in Knoxville Tennessee. More than 30 years later, after observing hundreds of bodies decompose in a variety of circumstances, Bass does not appear any closer to answering the original questions, and has conceded that variability seems to be the only constant in relation to human decomposition (Bass 1997).

Few individuals in today’s society have had direct experience with death and fewer still with decomposition. Even at crimes scenes, the question “is that normal?” is often heard when police officers are faced with decomposed human remains. In a recent case in Richmond BC, the Sergeant asked me how the remains had been burnt, when the body was actually in the late stages of black putrefaction. The fact that skin de-gloves on land with the same frequency as in water is met with incredulity and the fact that fatty tissues can convert into malodorous soap; disbelief. The issue is that even the people who are tasked with dealing with death and decomposition do not know what the normal progression of decomposition is for any scene context. The result of this ignorance is that in Canada, death investigators have no way of knowing whether a body has decomposed in one context and been moved to another. These death investigators cannot recognize anomalous tissue changes, (i.e., due to trauma), as they do not know what normally is. Currently human decomposition is a complicated and mysterious event for most death investigators.

This knowledge gap relating to the normal progression of human decomposition has not been filled by the published literature. All of the human experimentation has been conducted in the United States, with the published studies being produced primarily from research conducted at ARF in Knoxville, Tennessee. Unfortunately, the results of the human decomposition research have been more founded on observation and conjecture as opposed to empirical experimentation (Bass 1997; Vass 2011). There have been a number of regional retrospective studies conducted in the United States (Galloway et al., 1989, Rhine and Dawson 1998) however they are environmentally specific (Galloway 1989) and suffer from small sample sizes (Rhine and Dawson 1998, Megyesi et al., 2005 and Sorg et al., 1998). Due to the lack of data for human decomposition in Canada, there is no way of knowing how geographical or ecological variability affects the progression of decomposition between regions, countries or continents.

The majority of the research undertaken to forward our knowledge of human decomposition has been conducted using animal proxies. Pigs have primarily been the animal of choice; however guinea pigs, rats, dogs and even kangaroos have fallen victim to the taphonomic researcher (Kočárek 2002, Reed 1958 and Forbes et al., 2005c). These animal proxies have been decomposed on land, in water, in graves, in stone crypts, in cars and in trees under an array of conditions and variables. As a discipline, we have gained considerable knowledge of the progression of pig decomposition. Unfortunately, it has yet to be established how pig decomposition is comparable to human decomposition.

As human decomposition is accomplished through the actions of enzymes and bacteria, temperature is the one variable which most researchers believe has the greatest influences on the overall rate of decomposition. That is where the agreement ends. Researchers have proposed a large number of variables which are suspected of contributing to human decomposition. Some of these variables include: tissue trauma; body size, rainfall; partial pressure of oxygen; sunlight; humidity; local faunal complexity; geology and meteorology (Gill-King 1997, Megyesi et al., 2005 and Sledzik 1998). As a discipline, there is no consensus of what variables or complex of variables contribute to the progression of decomposition in any scene context.

One of the principle aims of forensic taphonomy research has been to develop an accurate and reliable method of estimating the Post Mortem Interval (PMI) to refute or support alibis in criminal investigations. Due to the large error rates for the chemical methods used for the recent PMI interval, and the unreliability of the temperature (reduction of 1.5˚C/hour) or stomach content methods, forensic pathologists have relinquished this pursuit and currently depend on witness statements to establish a probable time since death (Polanen 2008). Forensic entomology has been used to create PMI estimations, however insects are seasonally limited and restricted from bodies in certain environments (i.e., indoors). There is hope that chemical analysis of decompositional fluids can produce a reliable means of PMI estimation, however this would only be applicable for bodies outside. Currently, there are no reliable or accurate methods to estimate the PMI based the biological or chemical analysis or visible state of human tissues after death.

The assumption is that PMI estimation based on the visible state of the body is unreliable as so little is known about the normal progression of decomposition and the factors which influence it. Vass (2011) however, with his proposed *Universal* formulas, begs to differ. Vass (2011) has proposed that two formulas based on a number of decompositional *constants* can be reliably used to estimate the PMI for all bodies on or under the surface everywhere.

The purpose of this study is to determine what the normal progression of human decomposition is for the outside, inside, water or burial context in Canada. The array of variables present at these scene types will be examined to determine what kind of variables and what complex of variables affect the relative rate of decomposition in those scene contexts. The aim of this study is also to determine whether there are differences in the rate of decomposition between regions and ecozones in Canada. The variability within the progression of decomposition, the variability between scene types and regions will be examined to determine whether or not it is reasonably possible to create a method of PMI estimation based on the level of decomposition for cases in Canada.

The practical application of this research is to give death investigators the answer to the question "what is normal?" and help explain why decomposition was faster or slower for one body compared to another in the same context. The last aim of this research is to gain a sufficient understanding of human decomposition to determine whether PMI estimation based on the visible state of the body is reasonable or responsible in a forensic context.

2. Literature Review

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). Traditionally the focus of physical anthropologists has been the personal identification of found remains based on the individual's anti-mortem biological profile. Researchers such as Mildred Trotter, T. Dale Stewart and Robert J. Terry (Beyers, 2002) spent their careers developing indices from museum or military osteological collections in an attempt to differentiate between the sexes, ages and 'races' based on the skeletal remains.

Since 1972, with the formation of the American Academy of Forensic Sciences (AAFS), new interest has been generated in the processes that affect the body after death. The goal of this new study of forensic taphonomy was to understand the natural changes which affect the body after death in order to differentiate them from man-made changes. It was realized very early on by people like William Bass (Bass and Jefferson, 2003), that as a discipline, very little was known about the soft tissue changes which occur during the post mortem interval. Forensic anthropologists like Bass were being asked questions by the police about the post mortem interval that they could not answer. It was this realization from a discipline standpoint, which prompted considerable experimental and retrospective research into human decomposition and the process which affect it over the next 30 years.

This literature review presents the current state of our understanding of human decomposition and the factors which affect it within the field of forensic anthropology with an evaluation of our ability to answer the death investigators questions at the scene or in the court room in a medico-legal context. This literature review will also identify the shortfalls and gaps in the published literature as it relates to forensic taphonomy at any death scene, but specifically as it related to scenes in Canada.

2.1. The Development of Forensic Taphonomy

Taphonomy as an area of study has been in the literature since the 1940s (Efremov, 1940) within the discipline of palaeontology. The word taphonomy was originally coined by the Russian palaeontologist I.A. Efremov in 1940. Palaeontologists were interested in the physical changes which occurred to organisms after death as a result of biological process or environmental variability. They were interested in the transformation and transportation of those remains in specific environments or geographic locations to better understand the processes that “operate on organic remains after death” (Micozzi 1991:3) and the creation of the fossil record (Weigelt, 1927). The focus of their interest was in the transferral of organic remains from the biosphere to the lithosphere (Olson 1962).

In 1927 Johannes Weigelt studied the contemporary deaths of mammals, birds and reptiles along the mudflats of the United States Gulf Coastal plain as an analogue for the formation of the fossil record in the distant past. This methodology was based on the theory of uniformitarianism which assumes that the natural laws and processes which occur today have also operated in the past. Weigelt’s publication ‘Recent Vertebrate Carcasses and their Paleobiological Implications’ (1927) provides an incredibly important link between reality and the process of mortality, transport, and burial with patterns of fossil accumulation in the vertebrate record (Behrensmeyer and Badgley 1988).

The paleo-archaeologists were interested in differentiating the changes to bone caused by scavenging or weathering from tool marks created by butchering or hunting activities (Shipman and Rose, 1984). The 1970s saw a dramatic increase in actualistic research into vertebrate taphonomy, which focused on such topics as transportation of remains (Wolff, 1973), bone weathering and deterioration (Behrensmeyer, 1978) (Bonnichsen and Sorg, 1989) and site formation processes (Voories, 1969). This new interest in the behaviour of early humans had an effect on archaeologists and physical anthropologists such as Binford (1981) and Shipman and Rose (1984) who attempted to understand the archaeological site formation processes in relation to lithic assemblages created by tool production or faunal collections created hunting, butchering and meat consumption.

Since the 1970, forensic anthropologists have begun to appreciate the usefulness of actualistic and experimental research used by the archaeologists to test the theories of site and artefact formation. Actualistic research and experimentation has been used during the past 30 years to investigate modification to the body as the result of natural or man-made variables at the death scene (Reed, 1958), (Payne, King, and Beinhart, 1968) and (Rodriguez and Bass, 1985). Forensic anthropologists today are not only interested in changes to the hard tissue, but also the soft tissue as it relates to informing investigators about context and the relative passage of time.

Hagland and Sorg (1997) have published the most current North American definition of taphonomy within forensic anthropology in their seminal volume: Forensic Taphonomy: The Postmortem Fate of Human Remains. Haglund and Sorg define forensic taphonomy as "the use of taphonomic models, approaches, and analyses in forensic contexts to estimate the time since death, reconstruct the circumstances before and after deposition, and discriminate the products of human behaviour from those created by the earth's biological, physical, chemical, and geological subsystems" (Haglund and Sorg 1997:3). Within Europe, the generally accepted definition of forensic taphonomy is simply 'the various alterations that take place postmortem' (Pinheiro, 2006:86). In their review of the most recent developments within the field of forensic anthropology, Dirkmaat et al. (2008) describes taphonomy as a means to strip away the changes caused by natural process and to differentiate human behaviour. The man vs. nature determination is critical, not only for trauma assessment, but also for the reconstruction of all the events which created the death scene upon recovery.

Although there seems to be general consensus in relation to the definition of forensic taphonomy there does seem to be variability in the stated range of research goals of this sub-discipline. Haglund and Sorg (1997: 3) list three separate research goals:

1. Estimate the time and circumstances since death;
2. Distinguish postmortem conditions which may serve to confound human identification and the determination of the cause and manner of death;
3. Identify factors which related to the survival of human remains and other evidence.

Komar and Buikstra (2008) propose five goals for forensic taphonomy:

1. Estimate the time-since-death;
2. Distinguish human from nonhuman agents of bone modification;
3. Understand selective transportation of remains;
4. Identify variables resulting in differential preservation of bone;
5. Reconstruct perimortem events and circumstances.

Dirkmaat et al. (2008: 39) describes three main research goals for forensic taphonomists:

1. Establish scientifically grounded estimates of postmortem interval (time since death), based on decompositional factors (primarily soft tissue, but in later stages may include bone modification factors), entomological evidence, chemical methods and associated physical evidence modification
2. Reconstruct of the original position and orientation of the body; and
3. Characterise of the role played by human intervention (as a taphonomic agent) on the remains, through the process of 'stripping away' (Gifford 1981) all other natural agents affecting the remains.

A review of these three different perspectives of the research goals for forensic taphonomy, suggests that Komar and Buikstra (2008) seem to be grounded in the more traditional research interests of paleontological taphonomy. The research goals proposed by Haglund and Sorg (1997) have a more contemporary forensic focus compared to Komar and Buikstra (2008) however, their research scope seems to be more limited compared to those described by Dirkmaat et al. (2008). The importance of investigating and reconstructing the original position and orientation of the body has hitherto never been recognized as an important research goal of forensic taphonomy although it is a critical task of the police investigators at the crime scene. This type information is important to police to substantiate witness or warned statements, as well as to focus the crime scene search for evidence.

Another very important difference between Haglund and Sorg's (1997) research goals and those of Dirkmaat et al. (2008) is that Dirkmaat et al. (2008) identifies the need for reliable, repeatable and scientific methodology to produce opinions to be presented in court. This need is directly related to changes that have occurred in the legal systems both in the United States and in Canada in relation to the admissibility of expert witness testimony and the validity of 'scientific evidence'. The Daubert (US) and Mohan (Canada) rulings in 1993 and 1994 have had, and continue to have, far-reaching impacts to all forensic disciplines. Science now has a legal definition and the opinions provided by scientists are evaluated based on their level of objectivity, reliability and use of accepted scientific methodology.

Of all three perspectives of the proposed research goals of forensic taphonomy, those presented by Dirkmaat et al. (2008) seem to be the most relevant and consider the needs of the courts for admissibility of scientific evidence. It is against these research goals that the success or failures of the current published literature in forensic taphonomy will be evaluated. The legal standards in Canada and the United States will be presented to determine whether or not current methods and results would meet, exceed or fail those standards. The current literature on forensic taphonomy will be presented and evaluated based on their methodology. There are three main types of methodologies used in the forensic taphonomy: actualistic human experimentation, actualistic animal proxy experimentation and retrospective studies of human death investigations. This review will also include an evaluation of relative success of other disciplines such as forensic pathology, forensic entomology or forensic chemistry to answer the questions posed by death investigators or judges at the scene or in the court.

2.2. Legal Considerations in Forensic Anthropology

Dirkmaat et al. (2008) stated that the introduction of forensic taphonomy has had a dramatic influence on all aspects of forensic anthropology. Much of the research which is being conducted in relation to forensic taphonomy is occurring outside the lab in the field with actualistic experimentation. The death investigators have realised the utility of utilizing forensic anthropology resources at the crime scenes. The questions that are being asked of these forensic anthropology experts in the field relate to the duration of the post mortem interval, the interpretation of any visible changes to the body as well as the traditional question of "who is this person and how did they die".

In order to better understand the natural processes of decomposition and modification to the body by environmental or ecological variables, researchers have turned to experimentation with humans and proxies as well as retrospective case reviews. The one critical distinction between forensic anthropology and anthropology is that any methods used to produce opinions in forensics must conform to the legal standards of science for the presentation of expert witness opinions in court.

There has been an increasing call for adherence to these legal requirements in the recent literature (Grivas & Komar 2008; Rogers 2005 and Christensen & Crowder 2009). The legal rules regarding the presentation of expert witness opinions were written and defined as the result of the Supreme Court decision Daubert vs. Merrell Dow Pharmaceuticals (No. 92-102 506 US 579, 1993) in 1993. The need for a clear definition of science was caused by subjective opinions being proffered by both defence and prosecution which were often contradictory. The credibility of the methodology was assessed based on the reputation or credentials of the expert and their results or opinions could not be validated or objectively replicated.

The Daubert case was the first in the United States to establish standards for the admissibility of expert evidence in the forensic sciences so that the court could evaluate the relative strength of the opinion based on the reliability and objectivity of the methodology as opposed to the expert. Daubert decision stipulated that the methodologies used had to have been validated by the relevant scientific community and published in peer reviewed journals. This is not to say that novel science or methodology could not be introduced to the court. Each novel methodology would be evaluated for subjectivity, reliability and dependability. Some of the scientific disciplines that were negatively affected were psychiatry and handwriting interpretations which were based more on subjective assessment than objective methodology.

The Canadian standard which controls the admission of expert witness opinions is the Mohan Ruling ([1994] 2S.C.R. 9). The Supreme Court of Canada declared that for the testimony to be considered expert "the subject matter of the inquiry must be such that ordinary people are unlikely to form a correct judgement about it, if unassisted by person with special knowledge" (Kelleher (village of) v. Smith ([1931] S.C.R. 672, p. 684). The Mohan ruling stated that the opinion had to be relevant to the case and necessary to assist the triers of fact. In determining whether an opinion is relevant or not, it must also be determined to be essential and reliable. The introduction of new methodologies was addressed by Mohan: “Expert evidence which advanced a novel scientific theory or technique is subjected to special scrutiny to determine whether it meets a basic threshold of reliability and whether it is essential in the sense that the trier of fact will be unable to come to a satisfactory conclusion without the assistance of the expert” (R v. Mohan [1994]:25). Very much like Daubert, the Mohan standard emphasizes the reliability of the methodology. The other critical standard of expert evidence in Canada is whether or not the information is useful to the trier of fact or necessary to the case. Hence, any taphonomic statement must, in the long term, meet the standards of Mohan and Daubert in order to have expert opinions accepted in a Canadian or American court.

There are researchers within forensic anthropology who have made great strides towards addressing the admissibly standards for forensic science. The development of ForDISC now in version 3.0 (Ousley and Jantz, 2005) and (Ousley and Jantz, 1998), (Ousley and Jantz, 1996) although there are recognized flaws with the methodology, has enabled forensic anthropologists to provide an opinion on the biological profile of an individual with a stated reliability factor. Forensic taphonomy however is more of an ‘experienced-based anthropological analysis’ (Christensen and Crowder, 2009:1213) which relies more on subjective observations rather than objective measurements. Error rates and quality assurance issues are more easily expressed with measurement based methodologies. As Christensen and Crowder (2009) point out, it is not necessary to meet a specific error rate for admissibility in forensic science, it is necessary to have a known error rate and be able to articulate that level of reliability in court so that the trier of fact can place the appropriate weight on that evidence or opinion. The methods used by forensic anthropology in the area of taphonomy need to comply with and conform to the rules for the presentation of expert witness testimony within their country. No longer is the testimony of the expert witness based on his credentials, experience or publication records, but rather on the reliability of their scientific methodology

2.3. Current Research

There are three main methodologies utilized by forensic taphonomists to investigate the processes of human decomposition: actualistic research using donated human remains, actualistic research using animal proxies and retrospective reviews of real death investigations. Each one of these methodologies has its advantages, disadvantages and logistical complications.

For obvious reasons, the most desirable but logistically challenging method is to use actual human remains for experimentation. The second most desirable, but only slightly less logistically challenging, is the retrospective analysis using actual cases of human deaths. The third and least desirable due to the uncertainties surrounding the use of animal proxies is the experimentation with pigs or other animals. The methodology for this study is the retrospective analysis of human decomposition from actual death investigations in Canada. This methodology is well accepted had has used by a number of researches (Galloway 1989, Komar 1989, Rhine & Dawson 1998, Megyesi et al. 2005 and Heaton et al. 2009) in the published literature.

The retrospective analysis study involves the data mining of all relevant data from police or medical examiner files of deaths which have occurred in the past. It is the access to these files which can be logistically challenging due to file storage or archiving issues between regions or agencies. The sensitive nature of the files, specifically if it is a homicide file, can put these types of files out of access to most individuals not having security clearance to those police environments. This is why the biggest retrospective study yet accomplished was the study by Galloway et al. in 1989 in Arizona with 189 cases. The biggest retrospective study in Canada to date involves 30 coroner cases (Hobiaschak and Anderson 1999) from British Columbia. This study consists of 358 cases from locations across Canada. It contains information on death scenes from outdoor (surface and buried), indoor and water scenes. The data taken from these files is by far the most complex with 36 different recorded variables. Many of these variables have been quantified to allow for an empirical analysis of the variability of human decomposition in Canada and the factors which affect it.

2.3.1. *Actualistic Research*

The use of actual humans in forensic taphonomy experiments will certainly be the more desired test subjects as it most closely approximates the conditions of the actual death scenes. As we can imagine, it is the most logistically challenging and socially controversial. The University of Tennessee's Anthropology Research Facility (ARF) was established in Knoxville, Tennessee over thirty years ago. ARF was established in 1980 and consists of an acre of land on University property. As a result of the of requests to medical examiners and funeral directors in Tennessee, William Bass's received his first donated body from a funeral home in May of 1981 (Bass and Jefferson 2003). Bass reported that by 1997 literally hundreds of bodies have decomposed at the facility (1997). These individuals have willed themselves or have had their bodies donated to the facility by their family. For these pre-donations, the bodies arrive at ARF in a natural state of decomposition with all relevant information surrounding their identity and circumstances of life and death. Lee Jantz reports that they currently have over 2000 of these cases on file and receive approximately 100 a year (Raymund, 2010).

Amidst social controversy and opposition from the local residents (Bass & Jefferson 2003:119), several other body farms have been opened by a number of American Universities over the last few years. Western Carolina University in Cullowee North Carolina opened the Forensic Osteology Research Station (FOREST) in 2006. Texas State University-San Marcos opened their Forensic Anthropology research Facility (FARF) in 2008. Most recently Sam Houston State University has opened a 247 acre facility called the Southeast Texas Applied Science Facility (STAFS). There are other forensic anthropology facilities planned in California, Australia and India.

Although these facilities are using the optimal test subjects for their experiments, there are a limitations and complications in recreating the conditions of a real death scene due to the legalities of death in today's society. A number of the cadavers used at ARF are unidentified or unclaimed bodies donated by the medical examiners where little or nothing is known about the person (Ousley & Jantz 1998). As a matter of process, most of these bodies have been autopsied and stored for an extended period of time in refrigeration units. It is very likely that the removal of organs and long term refrigeration has had an effect on the normal progression of decomposition. The cadavers donated through the funeral directors are because their families can't afford to bury or cremate them. Many however have already been embalmed. It has been known for a long time that embalming considerably changes and delays the natural processes of decomposition (Berryman et al. 1997).

At ARF researchers examine some of the factors which affect decomposition by changing some of the variables to see how much they affect the rate or type of decomposition. Some of these variables which were examined include; decomposition rates and soil chemistry on and under the surface, or in water (Table 2.1). There has been a multitude of variables explored but not all reported by Bass, as much of the work is being conducted by students producing research papers or post graduate theses that never seem to make it to publication (Bass 1997:182-3). We have seen a few publications in taphonomy, entomology or forensic chemistry being generated by Sam Houston State University (STAFS) (Aitkenhead-Peterson et. al., 2012 and Rippley et al., 2012). There have been 10 main publications directly related to decomposition of human remains from 1983 to 2011 (Table 2.1), all but one using data from research conducted at ARF.

Many of the papers produced from ARF relate to the chemistry and biology of death, publications describing soil chemistry (Vass and Bass 1992), odour analysis (Vass, et al. 2008), or the bacterial triggers for the development of adipocere (O'Brien and Kuehner 2007). Only three publications have dealt directly with the description of human decomposition (Rodriguez and Bass, 1983), (Rodriguez and Bass, 1985) and (Bass 1997). This research is based on very small sample sizes (4, 6 and unstated numbers of bodies) and provides qualitative observations rather than quantitative results, which at the time was an entirely acceptable way to present their data in relation to a relatively unknown area of research. In Bass's latest publications, the descriptions of decomposition are not based on specific cases or empirical data, but rather his general observations at ARF over the last 30 years (Bass 1997).

Table 2.1. Actualistic Human Research

Author	Date	Number of subjects	Location	Results
Rodriguez & Bass	1983	4	Tennessee USA	First study using humans at body farm
Rodriguez & Bass	1985	6	Tennessee USA	Burial study – decomposition at various depths
Bass	1997	not stated	Tennessee USA	General summer/winter decomp.
Vass et al.	1992	7	Tennessee USA	Buried remains - soil analysis
Vass et al.	2002	18	Tennessee USA	Soil chemistry for PMI estimations
Vass et al.	2004	2	Tennessee USA	Odour analysis database
Britmeier, et al.	2005	87	Hanover, Germany	Effect of time, trauma and autopsy on decomposition of remains.
O'Brien & Kuehner	2007	3	Tennessee USA	development of adipocere
Vass et al.	2007	2	Tennessee USA	Odour analysis buried remains
Vass	2011	not stated	Tennessee USA	PMI Formula

The results of the research published by Rodriguez and Bass in 1983 and 1985 are that the cadavers decompose more rapidly in spring and summer due to insects and temperature and on the surface versus underground for the same reasons. In the summary of results for over 22 years of research at ARF and hundreds of bodies, Bass stated that there is "still much to learn about this very complicated subject" (1997:181). In his summary he also stated that "outdoor decomposition rates in Tennessee, as they do in all areas, depend on many factors, especially temperature and rainfall" (1997:185). Bass acknowledged climate and environment to be significant contributors to the rate and manner of decomposition, and as such the research conducted at ARF may be limited in application to that or similar region.

Research using human remains outside the United States in other parts of the world is relatively rare. Breitmeier et al. (2005) reviewed 87 human cemetery exhumations in Hanover Germany to determine the practicality of exhumations for the re-examination of previously autopsied and interred human remains. Although this review involved human remains, all of the subjects had all been embalmed and decomposed over time within a controlled cemetery context. This research was not intended for use by forensic anthropologists for application to decomposition at death scenes.

Although these body farms are being used locally for training and research purposes, the majority of the research being conducted is by graduate students who may not publish their results. Therefore, the sum total of the contribution of research using actual humans in an experimentation facility is actually quite limited. Quantifiable and objective research is being carried out in relation to soil chemistry soil sciences, odour analysis or adipocere formation (Tibbett and Carter 2008; Bass and Sorg 1997) at these facilities, however the published results of research relating to human decomposition and the factors which affect it is limited and generally non-empirical. These non-empirical results limit it's used in a court of law and the regional conditions limit the application of these results to other geographical locations.

2.3.2. *Animal Proxy Decomposition*

Due to the cultural and logistical complications of using donated or willed human remains, it is often more convenient to substitute other animals for humans in decomposition experiments. There have been a minimum of 22 animal proxy studies published from 1958 to 2011 in a range of countries. A sample of some of these studies has been provided in Table 2.2. Much of this research is centered in the discipline of forensic entomology rather than taphonomy and as a consequence, much of the reported data on decomposition is more of an afterthought. Forensic entomologists conduct these types of experiments to assess the timing and succession of insects on animal proxies for specific geographic regions so that they can provide estimates of the PMI based on the insect evidence. The main proxy of choice has been pigs, however, based on cost and availability, a range of other subjects have been used for this type of research over the years.

Table 2.2. Animal Proxy Research

Author	Date	Number & type of Subjects	Location	Results
Reed	1958	45 dogs	Tennessee USA	Entomology study
Payne	1965	11 piglets	Southern USA	Entomology study
Shean et al.	1993	2 pigs	Washington DC. USA	Decomp. - Sun vs. Shade
Anderson & Vanlaerhoven	1996	6 pigs	B.C. Canada	Entomology study
Turner & Wiltshire	1999	3 pigs	Hertfordshire, UK	Effect of clay soils
Yan et al.	2001	3 pigs	New York, USA	Adipocere: lab water study
Kočárek	2002	Lab rats (no unknown)	Check Republic	Decomp & entomology
Archer	2004	40 stillborn piglets	Australia	PMI & extrinsic variables
Tibbet et al.	2004	cubes of lamb tissue	Laboratory, UK	microbial degradation of tissue
Hobiashak & Anderson	2004	6 pigs	B.C. Canada	water entomology
Centeno et al.	2005	2 pigs	Buenos Aires, Argentina	Entomology sheltered/non
Weitzel	2005	21 pigs	Alberta, Canada	Burial in stone cairns
Forbes et al.	2005c	pig, cattle, sheep, rabbit & Kangaroo	Austria	Formation of Adipocere
Carter & Tibbett	2006	sheep tissue	Laboratory, UK	microbial degradation in sandy loam environments at different temperatures
Wilson et al.	2007	30 pigs	Northern England	Decomposition in different soils and environments
Calce & Rogers	2007	10 pig skulls	Ontario, Canada	Blunt force trauma & taphonomy
Carter et al.	2007	1 piglet	Ithica, NB, UK	terrestrial ecosystems
Sharonowski, et al.	2008	18 pigs	Saskatchewan, Can.	Entomology - season & habitat

Reeves	2009	3 pigs	Texas, USA	Avian vulture taphonomy
Pakosh & Rogers	2009	120 pig limbs	Lake Ontario, Canada	submerged in plastic bags
Cross & Simmons	2010	34 pigs	Northern England	Trauma & effect on Decomp.
Horenstein, et al.	2010	8 pigs	Argentina	Entomology & PMI estimations
Anderson	2011	6 pigs	Alberta, Canada	Entomology-inside/outside

Pigs or piglets have been used as the subjects for 68% of the above research projects. Two of these studies utilized the body parts of pigs; limbs (Pakosh and Rogers, 2009) and heads (Calce and Rogers, 2007). It is important to consider that decomposition may be adversely impacted due to the absence or reduction of gut flora bacterial in disarticulated body parts. As the result of logistical issues, the sample sizes for these types of experiments are consequently quite small. The largest sample size was 34 adult pigs (Cross and Simmons, 2010) and 40 still born piglets (Archer, 2004). There have been a number of land-based animal proxy experiments undertaken in Canada. Anderson and VanLaerhoven used 6 pigs in Maple Ridge, BC to conduct entomology succession studies but also commented on the stages and progression of decomposition over time (1996). Anderson (2011) conducted entomology experiments in Alberta with 6 pigs examining the success and population of insects on pigs indoors and outdoors.

Descriptions of the stages of decomposition and time taken to get there have often been a by-product of forensic entomological research. Weitzel used 21 pigs in Edmonton to simulate archaeological burials near Lake Baikal in the Ukraine, but also commented on tempo and manner of decomposition during the experiment (2005). The total number of published studies is relatively low, with limited geographical coverage and small sample sizes.

The other issue with using animal proxies is that there is no published validation of the premise that human decomposition is similar to decomposition in other animals. Anderson and Hobischak have suggested that pigs are an excellent model for human decomposition due to their similar gut fauna and skin (2004: 206). This sentiment is echoed by other researchers Weitzel (2005), Petrik, Hobischak, and Anderson (2004) who use pig as a direct model for humans. Dent et al. (2003) has stated that that the use of pigs in burial decomposition studies has been demonstrated by Forbes et al. (2002 & 2003) as being able to "mimic the decompositional biogeochemistry of human beings" (2004:576). Even though the biochemistry may be similar, it has not been established that decomposition in humans looks similar or takes the same time or path to skeletonization as any other animal.

Hobischak and Anderson identified discrepancies in the process of human decomposition between human and pigs when they noted that adipocere developed more rapidly with pigs as opposed to humans in their freshwater experiment (2002:149). Although there has been research conducted on the visible changes in soft tissue and disarticulation of the body in water (Haglund and Sorg 2002), there has been no research examining the impact that immersion in salt or fresh water has on the gut flora of pigs or humans. Many of the studies involve the investigation of diatom testing (Di Guancamillo et al. (2009) or adipocere formation (Yan et al. 2001). Yan et al. (2001) did determine however, that the rates of adipocere formation were different for fresh water, chlorinated and salt water. They suggested that water content had an effect on the rate of oleic acid degradation due to the amount of bacteria "*in vivo"* (2001:613).

The gut flora of human and pigs may not be as similar as previously believed. Table 2.3 provides a comparison between dominant species of bacteria found in the human and pig gastrointestinal tract.

Table 2.3. Gut Flora Human vs. Pig

	HUMAN Bacteria	PIG Bacteria
Stomach	Rare; too acidic Helicobacter pylori	more base Helicobacter sp.
Lower intestine	2 species of Bacteriods B. fragilis B. thetoaiotaomicron	Lactobacilli & Streptococci S. faecalis L. acidophilus L. fermenti
Colon	B. fragilis - dominates Cl. perfringens E. coli - present	E. coli - dominates

Note: Compiled from (Dierick, et al.,1986) and (Deirick, et al., 2002), (Drasar, 1974), (Collee, 1974) and, (Sears, 2005).

Based on the information presented in Table 2.3, there does appear to be a discrepancy in the literature as it relates to the similarities between human and pig gut flora. The body mass and distribution of fat and tissue on the body of a pig compared to a human is also quite different. Pigs have a larger thorax mass with a higher concentration of body fat. Based on differences in body composition and gut flora, it may be possible that pigs are not a direct proxy for human in relation to decomposition. This in itself adds a level of complexity to proxy studies using pigs, and particularity the conclusions drawn from them.

Many of the other species used for experimentation have been chosen for convenience due to their small size (cubes of lamb tissue, sheep tissue), or economy as they were free (rabbits, lab rats, guinea pigs, dogs, kangaroo, toads and lizards). In test subjects such as rabbits, rats, dogs and kangaroo's, the outward signs of decomposition would resemble more of a tissue loss and overall deflation due to the fur/hair, as opposed to the tissue colour, texture and cohesion changes seen in humans. In 1958, Payne stated in his conclusions that dogs are not appropriate as a model for humans due to it body size and fur which concealed many of the changes affecting the soft tissue. Mann et al. (1990) has observed that dogs tend to decompose at a faster rate than humans leading them to conclude that “studies on the decay rate of dogs at the University of Tennessee have not been shown to be comparable or valid substitutes for human studies” (Mann, Bass, and Meadows, 1990:110). The same issue exists for the use of these test subjects as with the pigs. The validity of the application of the results of this research to human forensic contexts has yet to be determined.

The focus of many of these actualistic animal proxy experiments (40%) were conducted for the purposes of creating regional forensic entomology models. Many of them do provide observations on the types and rates on decomposition as it relates to insect colonization and succession. As this is not the focus of their research, these observations are descriptive and general in nature. The areas geographically represented are; Alberta (Anderson, 2011, Weitzel, 2005); Ontario (Calce and Rogers, 2007, Pakosh and Rogers, 2009); Saskatchewan (Sharonowski, Walker, and Anderson, 2008); and British Columbia (Anderson and Hobischak, 2004). The two studies conducted in Ontario utilized portions of pigs, either heads or limbs. The study using pig limbs investigated decomposition of body parts in plastic bags in Lake Ontario and the other ability to discern blunt force trauma from taphonomic changes on pig heads. Both of these studies are highly specialized in focus using small sample sizes with very focused and limited results.

The terminology used by these researchers to describe the various stages or states of decomposition is not standardized, which makes comparisons between studies difficult. Many of these studies examined basic environmental variability such as sun/shade (Shean, Messinger, and Papworth, 1993) or effects of burial environment (Wilson, et al., 2007, Turner and Wiltshire 1999), and due the their small sample sizes do not have the ability to control for the multitude of complex variables which may or may not affect the process of decomposition of a body at a crime scene. Replication of these studies to assess the reliability of their observations in relation to the interpretation of the impact or outcomes of certain variables would be useful.

Research on human decomposition using animal proxies has been generally the product of forensic entomology research. The result of this type of research is generally descriptive and subjective with a lack of accepted terminology for the stages of decomposition which makes comparisons between research projects difficult. Much of the published results are focused on specific research questions which may limit their applicability to other research goals. The fundamental issue with this type of methodology is that we have not yet established and quantified the differences between human decomposition and other animal proxies. As a result, research resulting from this methodology cannot be applied to the forensic context without a known error rate or statement of reliability, or for that matter, confidence at a qualitative level.

2.3.3. *Retrospective Examination of Human Death Investigations*

A number of retrospective studies have been published examining the development and circumstances of human decomposition (Tables 2.4 & 2.5). Retrospective studies involve the data mining of police or medical examiner/coroner death investigative files. Information relating to decomposition has been taken from reports and in some instances photographs of the body at the scene or autopsy. Eight of these studies involved the investigation of human decomposition on land, and eight in the water. The majority of these studies were published between 1989 and 1999 with the most recent being published in 2009. There are multiple case studies in the published literature describing the conditions and peculiarities of a specific case, only the most commonly references studies and the studies most relevant to this study have been presented in Tables 2.4 and 2.5. The limit for inclusion in this literature review was a minimum of five cases based on the usefulness of the anecdotal results.

One of the great difficulties in conducting this type of research is access to police and coroner/medical examiner death investigative files due to sensitivity and confidentiality of the information. The researcher must have the appropriate level of security clearance, and these individuals usually work with the medical examiners officer or corner service. The researchers who do work with the police are generally forensic anthropologists who would only have access to the files that they have been asked to work on, which is generally found human remains cases. These researchers would not normally have access to a range of different types of death scenes in a range of contexts. This fact is reflected in the literature where the majority of the subjects for the retrospective studies are unidentified human remains recovered from outdoor scene, on the surface, buried or in water. Only two studies (Galloway et al. 1989, Megyesi et al. 2005) have investigated the process of human decomposition indoors. Due to the sample selection, there is a much larger focus on bodies decomposing outside with insect involvement after a relatively long post mortem interval of time as these are the type of cases attended to by forensic entomologists and anthropologists.

Table 2.4. Retrospective Studies: Land

Author	Date	No. Sub	Location	Results
Galloway et al.	1989	189	Arizona, USA	Classification system for arid environments
Komar	1997	10	Alberta, Canada	Winter decomposition - effect of scavenging
Haglund	1997	53	Pacific NW, USA	Scavenging disarticulation model for searching
Manhein	1997	5	Louisiana, USA	5 types of burial - adipocere development
Sorg et al.	1998	34	Main & Vermont USA	Cadaver dog efficiency – no description of decomposition or PMI
Rhine & Dawson	1998	50	New Mexico USA	Decomposition description for area
Prieto et al.	2004	29	Spain	Description of decomposition
Megyesi et al.	2005	68	all over the USA	Introduction of ADD to estimate PMI

Due to the nature of the research question, some of these studies have a narrow focus with limited information on the levels or states of decomposition. The focus of these studies include predicting recovery sites in fluvial deaths (Bassett and Manhein, 2002), cadaver dog efficiency (Sorg et al., 1998), or whether drugs or alcohol were present in bodies recovered from the New York water ways to suggest manner of death (Lucas et al., 2002). The sample sizes for these types of studies can be relatively small due to the enormous task of accessing the files and mining the relevant data. The average number of specific subjects reviewed for the land based studies is 59 cases and 87 cases for the water based studies. The quality and usefulness of the data in these files can sometimes be questionable due to inadequacies in the investigation poor recording of data at the scene or lack of universal terminology, i.e., advanced decomposition to one person can mean something very different to another.

The land based study conducted by Galloway et al. (1989) was the first of its kind and still stands as the landmark retrospective study on human decomposition. The research was conducted in Arizona and used the largest number of cases (189). More than twenty years later, this study is still the largest of its kind. This study took a comprehensive approach to understanding the decomposition sequence in their region and created a classification system to describe it (unfortunately, and not without the warning of Galloway et al. (1989), other researchers have used applied this arid classification system to very different types of ecosystems (Weitzel, 2005)). The results provided guidelines for interval since death estimations based on the decay process in the arid Southwest. Their study provided general guidelines or 'rules of thumb' for the arid regions of Arizona. Reliability and confidence rates are not discussed; however this study was published long before the Daubert and Mohan standards for scientific evidence were contrived.

The only other regionally based human decomposition study in North America was conducted in New Mexico by Rhine and Dawson (1998) using a total of 50 cases. The results of Rhine and Dawson appear to be fairly inconclusive with a large time range for each stage of decomposition. In one of their figures (1998:152) the level of decomposition from 0 to 5 can be found anywhere from 0 to 44 weeks in time (12 cases or 34% of the cases) and a level of stage 10 to 15 decomposition can be found from 2 to 52 weeks (20 cases or 57% of the cases) since death. It is interesting to note, that although the study involved 50 cases, only the data from 35 cases has used to create this figure. In their conclusions Rhine and Dawson describe decomposition in the New Mexico region as "curvilinear, with a great deal of variability between the fourth and twelfth weeks" (1998:152). However, their results indicate that there does not appear to be a relationship between decomposition score and time since death. The pattern in Figure 2 is linear rather than curvilinear and presents a large number of cases ranging from stage 10 to 14 in decomposition score with a post mortem interval of 3 to 52 weeks in time. The focus of this study is more on the deterioration of bone than the liquefaction of soft tissue. Therefore this study provides us with limited information on the regionally specific progression of soft tissue decomposition in this geographic area.

Haglund (1997) examined 53 forensic cases from the Pacific North West region of the United States, however the focus of this research was on impact of scavengers as opposed to the description of human decomposition in this geographic region. He examined the progression of disarticulation by scavengers to provide baseline post mortem estimations for investigators. The study involved a relatively small sample size with a known post mortem interval (37 case) and the error rates ranged from 5 to 52 months for his methodology of estimating the post mortem interval based on the extent of scavenging (Haglund 1997).

Rhine and Dawson (1998) determined that based on their New Mexico study, in combination with the studies from the Northwest (Haglund 1997) and Southwest (Galloway et al.,1989), this data provided a general template for rates of decomposition which could be applied continent-wide as a first order of approximation. They suggested that the practitioner could estimate the post mortem interval by “reference to the principles established by these studies, filtered through a set of local documented cases to set a baseline for the area” (ibid 1998:186). However, the small sample sizes, the large error rates and the regional applicability calls in to question the application of some of this data to other parts of the United States, other countries or even to the study area itself.

The latest and most current retrospective case study was published by Megyesi et al. (2005) and has made a significant contribution to forensic taphonomy with the introduction the method of calculating the ‘Accumulated Degree-Days’(ADD) score for the body. Megyesi et al. (2005) proposed that temperature was a more useful independent variable for the progression of decomposition compared to time. The ADD score is the sum of the average daily temperatures which the body is exposed to during the post mortem interval. For simplicity in the calculation, the negative mean temperatures were not included in the ADD score. To validate the usefulness of the ADD score versus the Post Mortem Interval (PMI) in days, Megyesi et al. (2005) examined 68 forensic anthropology/entomology case files contributed by the authors from various locations all over the United States. The majority of cases were from Indiana and Illinois (41%). A total of 57 cases were from outside scenes, and the remaining 11 inside residences and structures. These authors adapted the decompositional classification system from Galloway et al. (1989) and constructed a classification system for each portion of the body which is used to produce a cumulative Total Body Score (TBS). The results of their study were that temperature (ADD score) demonstrated that temperature accounted for 85% of the variability in the TBS compared to 74% for time.

The concept that the accumulation of temperature over time would have a bigger effect on the rate of decomposition is seemingly intuitive. However the there have been multiple studies conducted attempting to replicate this level of correlation with limited success. Heaton et al. (2009) in a study involving bodies recovered from two waterways in England and Scotland found a correlation of R^2= 77% for the ADD score and decomposition. They stated that there were issues with the subjective nature of the TBS classification system suggesting the scores were assigned on a “best fit” basis. A study conducted by Fitzgerald and Oxenham (2009) in Australia using pigs found time to be a more useful variable than the ADD score. As they were using data loggers with their pigs at the scene, they found there was a large discrepancy between the temperatures taken at the site for the pigs and those temperatures recorded at the closest weather stations. Finally, the review of multiple decomposition studies in Britain by Simmons 2010 found a correlation of 34% for the ADD score and decomposition in buried, inside and submerges scenes. The correlation of temperature and decomposition for the outdoor scenes was slightly higher with 67%.

The use of the ADD score needs further validation as the main dependant variable for human decomposition. There may be issues with the subjectivity of the classification system or unanticipated issues resulting from the exclusion of freezing temperatures in the calculation. This failure to take into consideration the negative impact that freezing has on autolysis and putrefaction (Micozzi 1997) may have negatively affected the predictive potential of the ADD score to explain the variability in decomposition. It may not be possible to use of this method in colder geographic areas such as Canada due to the greater extent and relative impact of extremely cold temperatures in winter in most areas of Canada.

Outside of North America, a study was conducted by Prieto et al. (2004) using only 29 cases to describe human decomposition in Spain. This study attempted to examine the contribution of 20 variables with only 29 cases using analysis of variance (ANOVA) and nonparametric test (Mann-Whitney) analysis with questionable results. Their phases of decomposition started at putrefaction and progressed through three stages of skeletonization with mummification phase 5 and adipocere formation at phase 6. They state that ‘human decomposition is a continuous process’ (Prieto et al. 2004:3), however it has been well demonstrated in the existing literature that mummification can be present on a body well before putrefaction (Galloway et al.1989) and certainly specific conditions must exist for the development of adipocere (O'Brien and Kuehner, 2007). The issues with this study are their unconventional classification system, small sample size with a large number of variables.

There has only been one land based retrospective study examining human decomposition study in Canada. Komar (1998) examined 20 cases in the Edmonton Alberta area. This data was taken from the Medical Examiner's records for cases of recovered human remains discovered during the winter months from 1990 to 1996. All of the individuals in this study were in the advanced stages of decomposition with partial to complete skeletonization. Of the 20 bodies in the study, 11 were found in a wooded context, 7 from the North Saskatchewan River and two in burials (one of these cases, a bear had discovered the body and consumed the majority of it). Of these 20 cases, only 10 were selected for the analysis. The post mortem intervals ranged from six weeks to 8 years. There were only three stages of decomposition described, advanced, partial and complete skeletonization. A total of 12 cases were discovered within one year of the individual's disappearance, however in Table 3, only the PMI and decomposition data has been provided for 10 of the cases. Interestingly there are two cases that have been classified as 'moderate' degree of decay. In 6 out of the 10 cases individuals went missing in summer and were recovered during winter. The issue is again that the body may have been in this stage of decomposition of an extended period of time. For two of the 10 cases, the individuals went missing in summer and were recovered in summer (May – August). There are only two cases where the individual went missing on land during the winter (December to April), these remains were 'extensively' damaged by scavengers (only a few bones left), bringing up the question of how Komar could determine, based on two cases that "decomposition to skeletal remains may occur in less than six weeks in moderate summer temperatures and in less than four months in extreme winter conditions" (1998:60-61).

There have been two studies published in Canada related to human decomposition in fresh water from 1995 to 2000 in British Columbia. The first study involves the examination of 30 coroner death investigations where the bodies have been recovered from fresh water (Hobischak and Anderson 1999). Information for the study was taken from written records such as coroners and pathology autopsy reports. It does not appear that Hobischak and Anderson had access to photographs of the body at autopsy or at the scene and subsequently did not have the opportunity to objectively evaluate the level of decomposition themselves. The main focus of this research was to identify a need for further research in the area and to identify issues with the quality of information recorded by investigators in relation to the state of decomposition and associated entomological activity. As such, there was no attempt to classify the level of decomposition and only general observations were made for these 30 cases. The observations included such things as the presence or absence of specific characteristics such as: silt, mould, tongue protuberance, foul odour or 'washer woman skin' (ibid 1999:102). The authors concluded that "there was a great paucity of information available for most of the cases discussed, high-lighting the need for further work in this area" (ibid 1999:105).

Table 2.5. Retrospective Cases: Water

Author	Date	No. Sub	Location	Results
Haglund	1993	11	all over USA	Disarticulation patterns: salt & fresh water
Sorg, *et al.*	1997	12	Gulf of Maine, USA	Taphonomy in the ocean - sea creatures
Boyle	1997	93	Monterey Bay, USA	Regional decomposition sequence
Hobiaschak & Anderson	1999	30	BC, Canada	fresh water decomposition/entomology
Lucas, *et al.*	2002	123	New York, USA	Alcohol & drugs to determine manner of death
Bassett & Manhein	2002	233	Mississippi River USA	Fluvial transportation & predictive modeling
Petrik, et al.	2004	12	BC, Canada	fresh water decomposition/entomology
Heaton et al.	2009	187	UK waterways	Estimation of post mortem submersion

Another study focused on the freshwater deaths within British Columbia (Petrik et al., 2004) (Table 2.5). A total of twelve cases were used in this retrospective study. Seven of the cases were examined from film footage or still photographs of underwater recoveries made by the Canadian Amphibious Search Team (CAST). The information for the other five cases was taken from a survey check sheet that coroners filled out for the five cases. The information for this study was compiled very much like the previous 1999 study, a check list of specific and potentially non-related characteristics, this time with the addition of two new characteristics: 'contact lividity' and 'eyes open'. Two characteristics from the 1999 study have been removed: 'fluids leaking' and 'insects'. There is no definition for these characteristics or description as to how they were scored. As identified by the authors themselves, one of the central issues for both of these studies was the quality and quantity of data that was available to them. The material for these studies was observations made by coroners on questionnaires or pathologists in their reports. Due to the lack in standardized terminology and range of experience with decomposition, the descriptions of decomposition would vary and mean one thing to one person and another to someone else. Petrick et al. (2004:16) admitted that due to the extremely small sample size, no definitive conclusions could be made.

These three publications (Komar, 1998) (Hobischak and Anderson, 1999) and (Petrik, Hobischak, and Anderson, 2004) represent the sum knowledge of human decomposition in Canada. As it currently stands the present literature contains a grand total of 52 actual human death investigation cases in Canada; 47 from water scene (including 5 cases from Edmonton), and 3 from scenes on land (including 1 burial), recorded in the Edmonton, Alberta region. The majority of the information for these cases is very limited, especially related to the water cases which represent 90% of the data. The results from these three studies are inconclusive due to the extremely small sample sizes. No real results were produced, and as such, no statement of reliability provided. Almost all of these studies, whether conducted on animal proxies, cadavers or investigative files are plagued by the same issues: sample sizes and detail and reliability of the data.

2.4. The Biological Progression of Human Decomposition

The focus of this study is on the biological changes occurring to soft tissue. For the purposes of this study, human decomposition commences at the point of death and ends with the colliquation (liquefaction) of all soft tissue resulting in skeletonization.

2.4.1. *Death and the Immediate PMI*

Shortly after death there will be no visible change. There is no colour change and no visible signs of decomposition. Death is generally considered the point at which the cardiac, brain and respiratory activity stops. This is referred to as somatic death (Nafte 2000). Forensic medicine divides death into two phenomena; "abiotic" with the cessation of vital activities and "transformative" causing the degenerative modification of the body (Campobasso 1998). The abiotic period includes body cooling, hypostasis, rigor mortis, dehydration and acidification. This phenomenon occurs within hours and days after death, for a comprehensive review, see Henssge et al. (1995).

Human decomposition begins approximately 4 minutes after somatic death (Vass et al. 2002). Tissue decomposition is facilitated by two processes; autolysis or self-digestion, which is dominated by enzymes and putrefaction which destroys the soft tissue through bacteria, fungi and protozoa. Different parts of the body decompose at different rates: "intestines and stomach, liver, spleen and brain decompose early, lungs, heart, kidneys, bladder, prostrate, testis, uterus and ovaries later" (Mant, 1984; Gordon et al. 1988 in Allison and Briggs 1991:31). The signs of putrefaction will become visible first in the abdomen. The two processes of autolysis and putrefaction will be discussed separately.

2.4.2. ***Autolysis***

Autolysis involves the action of enzymes. Due to the failure of biosynthesis, fermentation using lactic acids increases the acidity and activates hydrolytic enzymes which denatures the cell. The cells lose cohesion and release water. The breakdown of the cells also releases carbohydrates, proteins and fat which will later fuel putrefaction. As the cells of the body are deprived of oxygen, the carbon dioxide concentration increases which results in a decrease of blood pH and waste which poisons the cells (Vass et al. 2002). Cellular enzymes such as lipases, proteases and amylases dissolve the cells from the inside, rupturing the cells causing the nutrient rich cellular fluids to be released. According to Vass et al. (2002), the cells with more enzymes and water (liver and brain) are affected more quickly; however autolysis will deteriorate all cells in the body.

The First Signs of Tissue Change

The bond between the epidermal and dermal layers of the skin release and fluids collect between these two layers creating epidermal bullae and skin slippage. Lividity and settling of blood cells in the veins and arteries may become visible at this time. The blood will still have a red to dark red discolouration. An increase in the acidity of cellular cytoplasm which triggers the depletion of Adenosine triphosphate (ATP) creates rigor mortis (stiffening of the tissues). Once the process of autolysis has created sufficient quantities of nutrient-rich fluid from cellular disruption, putrefaction will take over to self-digest and liquefy the soft tissue (Vass et al. 2002 & Gill-King 1997). During this stage, desiccation of the fingertips or appendages can cause a black or brown discoloration. This is not to be confused with black putrefaction.

2.4.3. ***Putrefaction***

Putrefaction is the biological process which liquefies us. The mechanism of putrefaction consists of our own enteric anaerobic bacteria. This fermentative process is fueled by the carbohydrates, proteins and fats released by autolysis. Autolysis creates an almost anaerobic environment which favours the growth of bacteria in the large intestine. According to Gill-King, these bacteria consist of 96 – 99% anaerobes (e.g. *Bacteriodes* spp., anaerobic lactobacilli, clostridia, and anaerobic streptococci) (1997:99). The other component, the aerobes (1 - 4%) (e.g., gram negative coliforms, enterococci, and small numbers of *Proteus* spp. *Pseudomonas* spp and others) (Jawetz et al.,1992; Gill-King 1997). This process creates gasses (bloating), alcohols, acids and colour changes due to the decomposition of blood and bile pigment in the tissues changing colour with increased acidity.

Esherichia coli are the dominant coliform organism in the gut (Wilson 1974). The flora is affected by “the blood supply, the degree of moisture, the temperature of the part concerned, the pH or Eh values, the production of fatty acids and the various secretions having a stimulating or inhibitory effect on different organisms” (Wilson 1974:3). The endogenous fungi, bacteria and protozoa of the body break down the remaining tissue to gases, liquids and simple molecules. Due to the buildup of various gasses (hydrogen sulfide, carbon dioxide, methane, ammonia, sulfur dioxide, and hydrogen) in the body cavities (particularly in the lower digestive tract) the body will start to bloat. The fluids and gasses will vent if possible through any natural or introduced bodily orifices.

The bacterial fermentation of carbohydrates produce gases and organic acids such as lactic, acetic, acetoacetic and propionic acids (Gill-King 1997) which are responsible for the early acidic environment of a decomposing body. Other products of fermentation include alcohols such as ethanol, butanol and acetone (Davis et al. 1985). This can make the detection of alcohol ingested by the victim prior to death difficult to differentiate from alcohols produced by fermentation (Helander et al. 1995). Anaerobic fermentation in the digestive tract produces volatile fatty acids like butyric and propionic acids. This process is dominated by aerobic and anaerobic bacteria. The amino acids and fats in muscles are digested by these bacteria into phenolic compounds and glycerols. "Compounds including indole, 3-methyl indole (skatole), putrescine, cadaverine, and various fatty acids have been detected and are significant decomposition products" (Vass et al 2002:542).   Putrescine and cadaverine are the two products responsible for the diagnostic smell of decomposition.

2.4.4. *Putrefaction - Colour Changes*

Colour changes are associated to putrefaction. Apart from the pooling of blood (livor mortis) creating a purple colour in the dependant portions of the body, there are two processes that create the different colours during putrefaction: the degradation of hemoglobin and conversion of heme to a series of bile pigments, and the formation of precipitates of H2S within vessels and tissues (Gill-King 1997:101). According to Vass et al. (2002:542), the first visible signal of the onset of putrefaction is a greenish discolouration of the skin due to the formation of sulfhemoglobin in settling blood.

Biliverdin is the pigment that changes colour depending on their oxidation state. At the onset of putrefaction, the green colour can be converted to blues and yellows in surface tissues due to the availability of oxygen. In an increasingly acidic environment, the green will move through shades of red towards brown. The last colours progress from brown to black. The black substance that is produced by putrefaction is ferrous sulfide which is a by-product of the reaction between iron and hydrogen sulfide (Gill-King 1997). The order of tissue decomposition starts with the digestive tract, heart and blood circulatory system which has the highest rates of ATP syntheses, biosynthesis and membrane transportation. The lungs and air passages are next, then the kidneys and bladder followed by the brain and nervous tissue. The last to decompose is the skeletal muscles and the connective tissues and integument which contain collagen (Gill-King 1997:87/98).

2.4.5. ***Colliquation and Skeletonization***

Skeletonization is the process by which the tissues liquefy as the result of autolysis and putrefaction to expose the bone. Tissues consumed by fire, maggots or scavengers are considered separate from the process of biological tissue decomposition. These bodies will exhibit the signs of late stage putrefaction with liquefaction of tissue in some areas of exposed bone.

2.5. The Classification of Human Decomposition

There are several classification systems currently in use to describe the visible levels of decomposition. Each one of them designed for a specific purpose such as forensic entomology (Payne 1965) or for specific environmental regions, such as arid environments (Galloway 1989) or geographic locations (Megyesi 2005). These classification systems can have as many as 21 possible stages (Galloway 1989) or up to thirteen stages for each major body part for a total of 35 separate stages. The classification system was designed by Galloway (1989) to specifically describe decomposition in arid environments, and although there have been attempts to use this system in other environments (Weitzel 2005), it should only be used to classify bodies decomposing in arid environments.

A number of studies (Archer 2003, Cross & Simmons 2010, Shean et al., 1993) have used the loss of weight to relate to the progression of decomposition, however it has not been demonstrated in the literature that tissue and weight loss occurs at a constant or even punctuated rate during the stages of human decomposition. The loss of weight has been used as a convenient measurement using animal proxies; however the validity of this methodology has not been established. The application of this methodology to forensic situations using actual human remains is not practical as the starting weight of unidentified (or even identified) remains is not known.

There have been a number of other researchers (Heaton et al., 2010), who have attempted to use the Total Body Scoring (TBS) system developed by Megyesi et al. (2005). The use of this system has been met with mixed success. Some of the issues identified were that rarely did a body exhibit all or even the majority of the states described by the classification system. This resulted in the investigators making educated guesses to select a category as “best fit” (Heaton et al. 2010:303). The issue with this classification system is similar to the one designed by Galloway (1989) in that it was designed based on the normal decomposition observed within a specific region; most of the cases used for the TBS system were from Indiana and Illinois. There was a lack of description and explanation for some of the qualifiers used within the TBS system. Classifiers such as: bone exposure with greasy substances; moist decomposition; sagging or caving in, may mean one thing to one researcher and something different to another.

Many of the classification systems used in relation to the pigs for soil analysis (Carter and Tibbett 2008) or forensic entomology (Anderson and Hobischak 2004) used a much simpler system of classification with only four stages of fresh bloat, active decay, advanced decay and remains based on Payne’s (1965) original six stages of decomposition. As the focus of the research is not necessarily the examination of decomposition, this four staged classification system is relatively vague without definition of the biological stages of decomposition. Many of these studies equated the amount of tissue loss to the amount of decomposition. Tissue is not lost at a constant rate from the point of death. The processes of autolysis and putrefaction take time to break down the biological components of tissue before the liquefaction process begins. Weight loss is also the result of insect involvement and the consumption of tissue by maggots. Insects may or may not colonize a body, and as a result, it is not part of the normal progress of soft tissue decomposition.

There is a need for a classification system which is relatively easy to use, which includes a standard terminology and explicit definitions for each stage of decomposition. The classification system should have a sufficient number of stages to accurately reflect the biological progression of decomposition. These two processes of autolysis and putrefaction can progress simultaneously; therefore it is the latest visible state that should be classified. The end result of autolysis and putrefaction is the liquefaction of the soft tissue the exposure of the hard tissue below. There are many classification systems of decomposition which include the colonization and succession of insects as a normal part of decomposition. Insect and scavengers consume rather than decompose the soft tissue.

Decomposition is regarded my most as a sequential continual and predictable process (Micozzi 1991; Nafte 2000; Rhine and Dawson 1998; Haglund and Sorg 1997b and Sledzik 1998). This process of decomposition is referred to in this study as baseline decomposition. This is the process, given optimal conditions that the soft tissue is biologically decomposed and is liquefied to expose the remnant hard tissues. If the environmental conditions are not optimal, too dry, too wet, with insufficient oxygen, or excessive acidity, then an alternate state of decomposition can occur. These alternate states can stabilize or preserve the soft tissues or decompose it by way of another mechanism. The three alternate states of decomposition recorded during this study were mummification, or desiccation of the tissue, adipocere formation and external moulding of the tissue.

For many classification systems, some of the alternate states of decomposition such as mummification or adipocere are included as part of stage definitions due to the environmental conditions within their geographical region. Mummification for example is an inevitable state in arid environment such as Arizona (Galloway 1989). For moist hot environments such as Knoxville Tennessee, adipocere formation may be an inevitable state of bodies decomposing in that environment (Bass 1997). These alternate states of decomposition act to stabilize the tissue and retard further decomposition due to its alkalinity with adipocere or absence of moisture in mummification.   Their appearance during the process of decomposition is entirely dependent on the environmental conditions. This can also be said for the presence of moulds on the exterior surface of the body which may be triggered by cool moist environments. It is necessary therefore to differentiate between baseline decomposition, and alternate states of decomposition caused by environmental variability.

2.6. Alternate States of Decomposition

Environmental variability can impact the normal progression of baseline decomposition and trigger the development of one or more of these four environmentally dependant states of decomposition: mummification, dry or wet moulding and adipocere development. Due to micro-environmental conditions, these alternate states of decomposition can occur simultaneously on different parts of the same body.

2.6.1. *Mummification*

Mummification occurs when the moisture in the tissue is evaporated directly into the atmosphere. Mummification will happen in a dry environment, either hot or cold. Different parts of the body can mummify if exposed to the elements while others will follow the normal process of putrefaction in a dry environment if covered or protected by clothing. Mummified tissue becomes resistant to decomposition and insects due to the absence of water.

2.6.2. *Adipocere Formation*

Adipocere is defined as a “postmortem chemical alteration of normal adipose tissue rendering it firm, grayish white and of wax-like consistency” (Cotton et al., 1987:1128). The process is also referred to as saponification due to the soap like hard brittle end product (Gill-King 1997). The formation of adipocere initially occurs just under the skin in the dermal and subcutaneous tissue, it later progresses to internal fatty deposits. Adipocere requires lipids and is seen more often in females, infants or obese individuals. Adipocere can form in dry environment, likely due to the presence of moisture already present in fat cells. Mant and Furbank (1957) noted the development of adipocere in a shallow burial in the desert after only a few days.

The formation of adipocere was attributed by Rhine and Dawson (1998) and Gill-King 1993 as the product of a damp environment, particularly in an oxygen reduced circumstance. Adipocere has formed on 100 to 150 years old bodies placed in a lead-lined coffin in above ground sealed cement vaults (Evans 1963). In 1957 Mant described several variables affecting the development of adipocere (Table 2.6).

Cotton et al. (1987) describes the process of the formation of adipocere. During the first days after death the endogenous lipases degrade triglicerides in the body to produce neutral fats. The bacterial *Clostridium perfringens* is present during putrefaction to convert these neutral fats into fatty acids and hydroxy fatty acids. The hydroxy fatty acids have a high melting point which contributes to the overall preservation of adipocere. The low pH (4.5 to 5.5) produced by the fatty acids stops bacterial growth which generally self-sterilizes and arrests the process of putrefaction contributing to the further stability of adipocere tissue (Cotton et al. 1987; Tomita 1984, Takatori and Yamaoka 1977).

Table 2.6. Variables Affecting Adipocere Formation

Effect	Factor
Enhanced +	Initial presence of fat
Inhibited -	Elapsed time between death and burial
Inhibited -	Autopsy performed before burial
Inhibited -	Body enclosed in a coffin
Enhanced +	Body clothed
Inhibited -	Straw in bottom of grave
no effect 0	Access of air to body after burial
Enhanced +	Mass burials
Enhanced +	Bacterial putrefaction
Enhanced +	Humid warmth

Note: Table created from (Mant & Furbank 1957) and (Cotton et al. 1987)

Temperature needed to develop adipocere had been much debated. Of considerable note, Tomita observed that *C.perfringens* does not grow in laboratory conditions below 70° F (21° C), however enzymes are active at much lower temperatures (1984). He also found it impossible to generate adipocere in a sterile environment. Simonsen (1977) proposed that adipocere tends to develop earlier and more extensively in warmer climactic conditions (1977). Cotton et al.'s (1987:1130) found that adipocere formed very rapidly during the time that water temperature exceeded 70° F (21° C), They speculated that if the bodies entered the water when temperatures were colder, adipocere formation would not have been so extensive. Two bodies recovered from the waters of the Duluth, Minnesota harbor in Lake Superior after five years resembled a shell of adipocere material encasing generally intact visceral organs (Cotton et al 1987). This hard shell of adipocere was also noted in Haglund's study involving 11 bodies recovered from a variety of water environments across the United States (1993).

According to Gill-King (1997), adipocere forms on the dependent parts of the body. The adipocere is a mixture of hard crumbly and soft paste-like varieties utilizing sodium or potassium. "When bodies are deposited in water or soils with high mineral content, e.g. calcium which is water insoluble, sodium and potassium may be displaced, producing 'hardening". Janaway (1996:70) describes recent adipocere as a soft greasy material which may be white or stained reddish brown. Old adipocere is white or gray and depending on its age and condition it has been likened to suet or cheese. According to Haglund (1993:812) fresh adipocere has a soft, greasy consistency; older adipocere may be hard and brittle". Haglund does admit that the terms which describe adipocere are so loosely applied and inconsistently defined as to sometimes preclude comparisons between retrospective cases. It appears there is also a lack of understanding between why some adipocere is hard and why the other is not.

Gill-King warns against using adipocere formation for PMI estimations as saponification appears to be a "sliding scale" (1997:103) between relative amounts of fat and water. When both are abundant, formation is "imminent" (ibid). Taphonomists interested in the fossil record have noted that recognizable adipose tissue may be preserved for over 1000 years (Sondheimer et al. 1966:221).

2.6.3. ***Moulding, Wet & Dry***

Wet moulding is the visible presence of fungi or algae on a wet substrate. These fungi or algae are presumed to have been introduced from the surrounding environment. Due to the variability in the fungal or algae species, the colour and distribution of fungi or algae can look different from one body to another or from one environment to another.

Dry moulding is the visible presence of fungi on a desiccated substrate. The substrate for this type of moulding is generally a dark red colour. It can occur in dry, cool environments. This type of moulding is often seen on bodies stored in coolers for a long time in the morgue. It is suggested that some of this fungal growth is the result of the unchecked growth of fungi already existing on the surface of the skin. Fungi, like athletes foot, of penicillin can colonize the body part as the immune system no longer holds its growth in check.

There has been research conducted on the colonization of fungi in relation to decomposition (Sagara et al. 2008), however the colonization of fungi in soil impacted by the decompositional fluids as opposed to colonization of the cadaver itself. Once the soft tissue has been removed, there are a number of keratinophilic species which colonize the hard tissue (Hudson 1972). There is little to no published data on the fungi which colonize the soft tissue on bodies decomposing on the surface. There does not appear to be any published information available on fungal growth in relation to buried bodies.

2.7. The Variables Which Affect Decomposition

There is consensus over which variables or combination of variables have the largest impact on human decomposition in any given scene type. Table 2.7 presents a sample of the list of variables identified by researchers which are considered to be significant to the progression of decomposition. The variables are provided in the table (2.7) in the order of perceived importance. Almost all of these authors would agree that temperature is the most critical variable. Decomposition of course is a biological process which is to a large extent temperature dependant. Most of the agents of decomposition such as enzymes, bacteria, and fungi have a nominal temperature and humidity range. Moisture is another variable which was identified by these researches as second only to temperature in importance. Time is another variable which has been investigated; time is of course directly related to temperature as the passage of time results in the accumulation of temperature.

After temperature and moisture, there does not seem to be agreement over the remaining variables. Insect and scavenger activity, extent of clothing, burial, soil pH, burial depth, trauma, body size, sun exposure and rainfall are some of the most common variables identified as being significant to the process of decomposition. Many of these variables have been identified based on observations of animal proxy or human experimentation. Very few of these assumptions have been empirically tested to establish their validity. This study attempts not only to establish what the normal course of decomposition is in Canada given the four main scene types, but also empirically examine which variables affect the rate of decomposition at those scenes.

Table 2.7. Variables Which Affect Decomposition in Order of Importance

Author	Date	Number of Factors	Description of Factors
Galloway et al.	1989	10	Temperature, moisture, exposure to insects, access by scavengers, confinement within a structure, burial, coverings/clothing, trauma, body weight and changes in body location
Mann, Bass & Meadows Rhine & Dawson	1990 1998	11	Temperature, access by insects, burial & depth, scavenging activity, trauma, humidity, rainfall, body size & weight, clothing, substrate, soil Ph.
Gill-King	1997	5	Temperature, Moisture, Ph, Partial pressure of oxygen, local chemical environment
Sledzik	1998	5	Climate, meteorology, geology, biological and cultural
Compobasso	1998	3	Temperature, burial depth, access to the body by insects
Weitzel	2005	5	Temperature, Humidity (rainfall), insect access, grave type and sub-soil temperature
Megyesi et al.	2005	7	Temperature, sunlight, humidity, rainfall, elevation, vertebrate scavenging, peri/post mortem injuries
Battan Horenstein	2010	6	Type and size of carcass, location (sun, shade), season, microclimate conditions, local fauna complexity and abundance, different investigators
Simmons et al.	2010	2	Insect presence and body size

Based on the nature of the retrospective analysis, it was not possible to examine some of the variables identified in Table 2.7. Information related to variables such as soil pH and substrate, meteorology, partial pressure of oxygen or local chemical environment were not recorded by death investigators at the time of recovery. Investigation of these variables is more suited for experimental studies.

2.8. Geographical Variability of Decomposition

Canada is the second largest country in the world with a very diverse ecosystem ranging from temperate rainforests to arctic deserts. Due to the random nature of the case selection process, not all regions or ecozones of Canada are represented in the dataset. The distribution of cases in general in Canada is related to the distribution of population densities as deaths generally occur near where people live. Even if a body is removed from the scene of the death, the distances are usually not too great to the dump site due to the risk of discovery during transportation. In Canada the larger urban areas are generally located along a northern border of the United States in more moderate environments. Edmonton Alberta is the exception to that rule and is the largest city, the most far north in Canada.

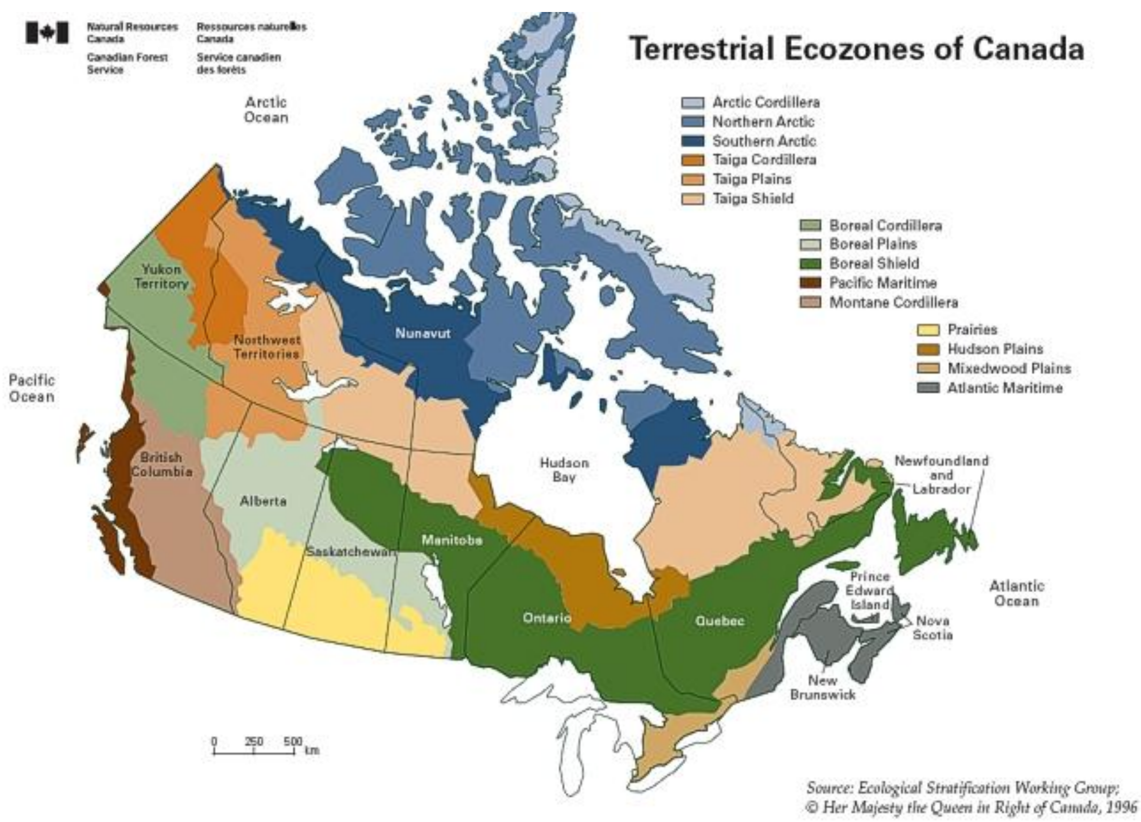


Figure 2.1. The terrestrial ecozones of Canada

Note: http://www.ccfm.org/ci/rprt2005/english/Terrestrial_Ecozones_of_Canada_Map.htm.
This reproduction is a copy of an official work that is published by the Government of Canada and this preproduction has not been produced in affiliation with, or with the endorsement of the Canadian Government.

The ecozones is a biogeographic region based on the distribution of ecology and terrestrial organisms. There are 15 ecodistricts in Canada as defined by the Federal Government of Canada (Figure 2.1).These ecozones are the largest units which are broken down into 53 ecoprovinces, 194 ecoregions and 1021 ecodistricts. For the purposes of this study the ecozones and ecodistricts were recorded for each case. Due to the number of cases in the study, only the differences between the ecozones were examined.

The two ecodistricts with the largest populations and the largest representation of cases are the Pacific Maritime (13) and MixedWood Plains (8). The population centre for the Pacific Maritime ecozone is the Lower Mainland of Vancouver which includes Metro Vancouver. This area has a population base of approximately three million people. As Metro Vancouver is located on the Pacific coast, its climate is mediated by the Pacific Ocean with summer temperatures averaging 13 degrees Celsius and winter -1.5 degrees Celsius. Precipitation can exceed 4000 mm in a year. The geography of this region is dominated by the coastal mountain range with a temperate rainforest flora. The MixedWood Plains on the other hand is an area of more climatic extremes and home to more than half the entire population of Canada. The average temperature in summer is 17 degrees Celsius and in winter the average is -5 degrees Celsius. The summer can be extremely hot and humid and the winter bitterly cold. The geography if this region is dominated by rolling hills with many lakes and water ways. The majority of the mixed coniferous and deciduous trees in the ecozone have been replaced over the past century by cultivated fields.

2.8.1. ***Post Mortem Interval and it’s Estimation***

There is the popular assumption in today’s society that we have the ability to estimate the point of death with relative certainty. This assumption has likely been propagated by entertainment industry with television shows such as Quincy or CSI. The public make the assumption that it is possible to determine the PMI based on body temperature, stomach contents, insects or level of decomposition. As time has passed and as some of these methods have been tested in a court of law, the reliability of some these methods have been called into question (Henssge et al., 1995). This is a brief review of some of the methods used to estimate the PMI and the variability of human decomposition. The current belief in Canada among death investigators is that due to this variability and the inability to predict the PMI in the later post mortem period, the most reliable means of estimation is based on the time and date the individual was last seen alive.

From an investigative standpoint, there are many reasons why we pursue this goal of estimating the post mortem interval. The main goal is the positive identification of the human remains. Due the large numbers of missing persons in the Canadian Police Information System (CPIC) at any one time, a time limit is needed to limit that list. With a smaller number of potential missing persons, dental records or fingerprints can be used to make a positive identification.

One of the other reasons given by researchers for the need for an accurate PMI is the testing of alibis; however only in very few cases is the timing of death critical to the investigation. In most cases, with the identification of the human remain remains and launch of the investigation, it is the police who determine the circumstances surrounding the death and determine the PMI based on records or statements.

The increasing use of CCTV and video footage during an investigation provides another justification for the generation of an accurate PMI. Due to the innumerable sources of video and digital footage from highway cameras, convenience stores to bank ATMs, the estimation of a tight timeline for the critical perimortem period is increasingly necessary for evidence gathering reasons.

2.8.2. ***Temperature Based PMI Estimations***

The temperature based method of estimating the time of death has been used at crime scenes or on autopsy tables from 1950 to the 1990 in Canada. It was not uncommon in the past to have a doctor/pathologist attend the scene to take a deep cavity temperature reading from the body to estimate the time of death. This method has was established in 1839 (Davey, 1839) and is based on the general principal that bodies cool at a predictable rate over time. As Knight points out “apart from the inherent fallacies and inaccuracy of the actual models and algorithms used to calculate the PMI, a number of external factors also contribute to errors in the final calculation” (Knight, 1995). Some of these external factors include ambient temperature, winds and draughts, precipitation and humidity, body posture, size, age and clothing or covers on the body. In an attempt to test the validity of this method, Knight conducted an experiment using 100 bodies with known post-mortem intervals. Two experienced forensic pathologists were instructed to take rectal temperatures or multiple readings over a period of 3 hours to estimate a time since death. The results of the study demonstrated that the forensic pathologists under-estimated the post mortem interval on a consistent basis. The true PMI was estimated correctly in only 11 out of 100 cases. During the study, the pathologists underestimated the post mortem intervals in 57 cases, and over estimated it in 32 cases (Table 2.8).

Today, the temperature method of PMI estimation has fallen into disuse due to its unreliability. Some other techniques which do show promise involve the chemical analysis of the changes within the vitreous humour after death, examining the rise of potassium (K+) concentrations (Coe, 1993), or hypoxanthine (Hx), or a combination of both (Madea and Henssge, 1995). However, errors introduced by the practitioners taking measurements, unfamiliarity or inexperience with complex methodologies, still results in unacceptably large error rates in the estimation of post-mortem period even in immediate 24 to 48 hours after death. The results for PMI estimations past that 48 hour limit are less reliable with a larger error rate (Madea and Henssge, 1995). Within the discipline of forensic pathology, any estimate of post mortem interval is provided with hesitation. The current consensus is that witness statements are still the most reliable means to determine a time of death.

Table 2.8. Error rates Using Body Temperature to Estimate PMI

Out of a possible 100 cases	**Error rate**
35	10%
54	20%
70	30%
90	40%
95	50%
2 cases	100% *

Note: The error rate was calculated as the interval increased. * An 1.5 hour estimation of a true 45 minute interval would constitute a 100% error. Adapted from (Knight, 1995).

> Determination of death time by the pathologist is seldom useful as evidence in criminal proceedings because of the non-predictability of the rate of post mortem changes, the lack of reproducible standards allowing correlation between post mortem interval and a post mortem change, and a wide variation in opinions when confronted with the same facts. It is a subjective opinion and little weight should be placed on it.
>
> Gouge inquiry Report (Pollanen 2008: 72-3)

2.8.3. ***Chemical Based PMI Estimations***

Vass (1992) has attempted to use the chemical analysis of decompositional fluids to estimate PMI in the later postmortem period. Vass and his team focused on oxalic acid as an indicator of PMI and found that concentrations in the liver, heart and kidney tissue are the most useful organs from which to obtain data. The method seems to be limited by accurate temperature information from the crime scenes and access to this diagnostic equipment by the death investigators. Another problem identified by Gill-King (1997) for post mortem interval estimations using bioassay is that sampling may be affected by “chemical sanctuaries” or “pooling” phenomenon (Gill-King, 1997:104) which will give differential results for different portions of the body.

The chemical components of soil solutions and the effect soil has on decomposition has been examined by various researchers (Vass and Bass, 1992), (Turner and Wiltshire, 1999), (Horsewell et al. 2002), (Forbes et al. 2005a) (Tibbett and Carter 2008) and (Dent et al. 2004). These chemical analyses of soils seem to hold great promise for the creation of methods to produce reliable PMI estimations. The only limitation of these methods would be the practical application by death investigations as none of these methods are commercially available. Other methods using UV fluorescence (Yoshino and Kimijima 1991), degradation of lipids (Contellano, Vellanueva and VonFrenkel, 1984) and (Cabirol et al. 1998) DNA degradation in hard tissue (Perry, Bass, and Rigsby, 1988), (Williams, 1994) and (Parsons and Weedn 1997) are being examined as potential methods to determine reliable PMI estimations.

A review of all the techniques to estimate time since death using hard tissue was conducted by Knight, (1969) and Pollard (1996). Some of the techniques described showed promise in distinguishing between archaeological and forensic bone. Levels of radioisotopes from nuclear testing accumulation in the bone of strontium-90 show promise as time markers, however these techniques require refinement and verification before they can be used with confidence. Swift et al. (2001) have examined the use of a range of radionuclides (238U, 234U, 210Po and 210Pb as well as 238Pu,239,240Pu and 137Cs) and trace elements (e.g. Pb) to estimate the post-mortem interval with relative success (Swift et al., 2001). In recent years the Bomb-pulse dating method (Ubelaker and Buchholz 2005) has provided forensic anthropologists with the ability to help differentiate those individuals who were alive before the 1950s and those who were alive after the atmospheric testing of nuclear weapons during the 1950s and 1960s. Bell et al. (1996) examined the microstructure and relative density of the skeletal microstructure and determined that changes did occur shortly after death but there was no rate of change. Many of these chemical and biological methods show considerable promise, however there is more work that needs to be done to ensure the reliability these methods in a variety of settings and conditions.

2.8.4. ***Insect & Scavenger Based PMI Estimations***

Forensic entomology has traditionally been seen as one of the most reliable methods to estimate PMI, (Payne 1965, Payne et al., 1968). However, the discipline is based largely on data gathered from decomposing pigs. The two basic premises of forensic entomology, as previously detailed, are that human decomposition and pig decomposition are similar and that insects will colonize the body immediately after death. These two premises have yet to be validated.

The ranges of factors, which influence entomological succession, are not entirely understood. Campobasso et al. 2001 have admitted that PMI estimations cannot be separated completely from the examination of corpse decomposition and that the chronology estimations are often imprecise due to the innumerable factors which affect both. Catts and Haskell (1990) have provided maximum and minimum estimates however, their accuracy is very much dependant on a better understanding of all intrinsic and extrinsic environmental factors affecting decomposition. PMI estimations in relation to water deaths using entomology have been deemed as “subjective and unreliable for legal testimony” (Hobischak and Anderson 2002). The other important issue with the use of forensic entomology to estimate PMI is that not all death scenes include the involvement of insects; in fact, in this study only 15% of cases outside and 7% of cases inside have any visible evidence of insects involvement during any season of the year.

Several individuals including Haglund (1991 & 1997), Haglund, Reay and Swindler (1988 and 1989) and Willey and Snyder (1989) have examined the rate of consumption and disarticulation of the human body by scavengers to create post mortem interval estimations. In his seminal work on the disarticulation of human remains in the pacific northwest of the United States, Haglund et al. (1989) created a continuum of disarticulation to generally predict the post mortem period. However, since the scavenging depends on random factors of opportunistic discovery, concentration of scavengers as well as seasonal variations, the techniques has very large error ranges, so much so, that it is of limited use to death investigators. There may be a limited use of this methodology in Canada as this study found that only 13% of the cases outside involved any kind of impact by scavengers.

2.8.5. ***The Universal PMI Formulas***

There are those forensic anthropologists who believe that PMI estimations are inherently unreliable (Nafte 2000) and constitute educated guess based the individual's previous experience (Galloway 1998, Rodriguez and Bass 1983, Mann et al. 1990) (Bass 1997). There are those however who believe it is possible to predict the PMI with a relative degree of reliability and accuracy. Vass (2011), after many years of research at the same body farm in Tennessee, has proposed a relatively straight forward method which can be utilized to produce PMI estimations for all geographic regions with the use of two simple formulas.

Vass has identified four variables: temperature, moisture, pH and partial pressure of oxygen which had the greatest effect on decomposition and attempted to quantify these variables to create a formula to estimate the PMI for all bodies either on or under the surface of the ground outside. The methodology is based on the premise that decomposition takes a standard amount of temperature, or relative time to complete. This maximum temperature has been calculated by Vass as 1285 ADD (2011:35). According to Vass when a body has reached 1285 degrees of accumulated temperature, the soft tissue of the body has completely decomposed leaving only the skeleton behind.

There are a few issues with the methodology described in the paper for the quantification of the variables and description of decomposition. For the classification of decomposition, Vass has used a method of assessing the amount of soft tissue in a state of decomposition on a 1 – 100% scale. This method was developed "based on years of observational data and experience" (2011:36) by Vass at the Anthropological Research Facility (ARF) in Knoxville. However, there is no specific explanation or description of what qualifies as tissue decomposition. It is unknown whether tissue decomposition consists of discolouration due to putrefaction, or absence due to liquefaction. This lack of clarity makes it difficult to relate these descriptions of decomposition to other studies by other taphonomy researchers.

Of the four factors identified by Vass (2011), temperature, moisture, Ph and partial oxygen pressure, he has provided a means to quantify only three of them. Vass has derived the constant factor of 0.0103 for the effect of moisture after "observing the effect of humidity on decompositional rates for over a decade [at the ARF]" (2011:36). A humidity score of between 1 and 100 is provided for bodies above ground and calculated based on "the average humidity at the site of discovery on the day the corpse is discovered" (*Ibid*). The temperature "can either reflect the average temperature at the scene corresponding to the day the corpse is discovered, or the average temperature at the scene corrected by a several day comparison to the nearest National Weather Service (NWS) station" (*Ibid*). The methodology to calculate an ADD, which is the cumulative addition of all positive temperatures during the entire PMI from the time of death to discovery, was not utilized, even though the terminal stage of decomposition is provided by VASS as an ADD score.

In relation to the two other factors; pH and partial pressure of oxygen, Vass addressed the level of oxygen by providing a ratio of 4.6 for a slowdown of decomposition in buried bodies due to a lack of oxygen. Vass calculated this ratio based on the study of 4 buried cadavers at ARF in 1985 (Rodriguez and Bass, 1985) and the decomposition of 3 pigs in clays soils in England (Turner and Wiltshire 1999). He also stated that "the value was determined by comparative experiments (over many years)" (2011:37). The contribution of pH in the process of human decomposition, although identified in the introduction as one of the four "widely recognized factors that influence the rate and ultimate completeness of the decomposition process" (2011:34) unfortunately was not mentioned further or discussed in the body of the paper.

Vass has proposed two different formulas for decomposition on and under the surface. In his paper, Vass examined the decomposition of two individuals from forensic cases and one test subject at ARF to validate the formula used to calculate the PMI for buried bodies. Two out of the three PMI's were estimated with a reasonable error rate. However there was an error of almost three years in the PMI estimate for the third case. Vass admitted the error did "illustrate the need for additional input by the forensic and scientific communities so that these models can be adjusted and corrected for varying environments and circumstances not yet evaluated" (2011:38). Vass does state that "these formulas have been found to work well in areas that encompass the mid to eastern section of the United States where humidity, soil moisture, soil type, and vegetation are similar to those studied at the University of Tennessee's Anthropology Research Facility" (2011:39). This statement is *slightly* misleading as the title of the paper gives the impression that the formulas are "universal" and could be applied to any body in any context.

Due to the jeopardy of misinforming and misrepresenting the ability of the 'Universal Formula" to estimate reliable PMIs based on the visible stages of decomposition to the forensic community in Canada; several of the premises of the formulas have been tested using the Canadian dataset. The premise of a constant 4.6 ratio of the delay in the decomposition of bodies under versus on top of the ground will be examined. The constant ratio of 0.0103 representing the impact of moisture on decomposition and the end stage of 1285 ADD score to represent the removal of all soft tissue will also be confirmed or refuted using the Canadian dataset. As a result of the study, an evaluation of the inherent variability of the progression of decomposition, regional and geographic inconsistency, and the identification of the factors which affect it in a range of scenes types such as indoors, outdoors, in water and in burials will determine the applicability and practicality of the application of any PMI methodology within Canada based on the visible state of the body.

2.8.6. *Conclusion*

As we have seen, there has been a limited amount of research conducted and published on human decomposition and the factors which affect it at death scenes anywhere in the world. There have been only a handful of publications (6) generated from the ARF in Knoxville, Tennessee since 1983 and only a few so far from the other American body farms. The literature being produced by research conducted at AFR in relation to human decomposition is generally based on subjective descriptions rather than empirically based experiments of quantifiable observations. Due to the potential for regional variability, the application of the research produced by ARF in Tennessee to Canadian should be thoroughly evaluated and tested. Unfortunately, there has not been an opportunity to conduct human decomposition experiments in Canada.

There have been many more experimental research projects published using animal proxies as opposed to humans in forensic taphonomy. There are three main concerns with this type of research. It still remains to be demonstrated that humans decompose in a similar manner or rate as other animal such as pigs. The focus of this type of research is generally not on the visible progression of decomposition, but rather forensic entomology, soil analysis or decompositional chemistry. Descriptions of the progression of decomposition are limited. The lack of a standard classification system or terminology makes it difficult to compare the results of these research projects. The last issue is that due to logistical issues, sample sizes are generally quite small. Due to small number of test subject, only one or two variable can be examined during any given experiment. Therefore, it has not been possible to examine the complexities of human decomposition at an actual death scene. The majority of the research published in Canada using animal proxies has been for the purposes of forensic entomology as opposed to decompositional studies.

There have been a number of valuable retrospective studies conducted during the past 20 years. Of the five published regional studies focusing on the description of human decomposition, only Galloway et al. (1989) has had sufficient sample sizes and quality of data to create in a useful regional standard. However even Galloway recognizes the limitations of this research to provide post mortem interval estimations. The sum total of the published data on human decomposition based on previous cases in Canada is extremely small. The study by Komar (1998) in Edmonton consists of five outdoor cases. Only two of these cases involve soft tissue decomposition. There is some basic information published on 47 water cases (Komar 1998, Hobiaschak & Anderson 1999 and Petrick et al. 2004), however, 40 out of those 47 cases were presented as part of forensic entomology studies and as such have extremely limited information relating to the stages of human decomposition.

The lack of consensus with decomposition terminology and classification makes the comparison between one study and another very difficult. The amount of information currently available for human decomposition in Canada is extremely small and relatively unreliable. With few exceptions, the research presented in the literature in relation to human decomposition is not based on empirical data and does not present results which are verifiable or reproducible. Some of the researchers since 2004 (Wilson et al., 2007, Megyesi et al., 2005 and Heaton et al., 2009) have attempted to address the issues of reliability and error rates in their research design and results. Although there are studies being conducted using empirical data for areas such as soil sciences or forensic entomology, there is still an absence of empirical data relating to the description of human decomposition in Canada using any of the main three methodologies.

In conclusion, there is no reliable data available which can be used to describe the normal progression of human decomposition and the factors which affect it in Canada. It is completely unknown how long that normal process of decomposition takes and if there is variability in the relative rate of decomposition throughout the continuum from death to skeletonization. It is unknown whether or not, or to what extent alternate states of decomposition such as mummification, adipocere formation or moulding occur on human remains in Canada. It is also unknown how the normal trajectory of human decomposition varies from one context or one geographical location to another.

2.9. The Aims of this Study

It has been demonstrated in the literature review that there is a limited understanding of the normal progression of human decomposition and the factors which affect it in any geographic region or environmental setting in Canada. There are four main of aims for this study. The first aim is to understand, define and describe the progression of typical or baseline decomposition in Canada. This baseline progression will be examined in four different contexts: indoors, outdoors, in a burial, and in water. The second aim is to identify which variables affect the progression of baseline decomposition in Canada. The third aim of the study is to establish whether there is variability in the pattern or progression of decomposition based on the geographical and ecological diversity within Canada.

Specifically, in point form, the following questions specific to the key research objectives are given below:

Part I. Define and describe decomposition in Canada

1. What is the *normal* progression of human decomposition in Canada?
2. Is there a qualitative or quantitative difference in the progression of decomposition occurring outside, inside, buried or in water?
3. What is the frequency and distribution of alternate states of decomposition such as mummification, moulding and adipocere formation at each scene type across Canada?

Part II. Determine which variables affect decomposition in Canada

1. Which of the two independent variables of accumulated time (PMI) or temperature (ADD score) has a more significant impact on the variability in the decomposition score in Canada?
2. Which independent variables have an impact on the variability of decomposition inside, outside, in burial or in water?
3. What complex of variables contributes to the variability in the decomposition score in the four scene types: inside, outside, burial or water?

Part III. Determine whether there is a geographical variability in decomposition in Canada

1. Is there a quantifiable difference in the time or temperature progression of decomposition between two ecozones of Canada?

2. Is it possible to associate an alternate state of decomposition to a specific geographical or ecological region within Canada?

Part IV. Determine the reliability and practicality of PMI estimations based on the visible level of decomposition in Canada

1. Can the “Universal Formula” (Vass 2011) be used to reliably predict the PMI for cases in Canada?
2. Based the biological, regional and site specific variability in decomposition; what is the potential to produce useful and reliable PMI estimations based on the visible state of decomposition for cases in Canada?

3. Methodology

3.1. Ethics and Research Permissions

In order to pursue this project, a number of permissions were obtained. Ethics permission was granted by Hal Weinberg, Director, Simon Fraser University, Office of Research Ethics at 3:39pm, 16/06/2006 (Application number 37235, for the project: "The Continuum of Human Decomposition and the Factors Which Affect it". The approval date was given as 19/06/2006 and assessed as minimal risk.

Additionally, permission was requested of the RCMP Behavioural Sciences Branch, using a letter and research proposal, to access specific information contained in the Violent Crime Linkage Analysis System (ViCLAS) database contributed to by all Canadian police agencies and managed by the National Police force: the RCMP. Permission was granted by Insp. L. O'Brien, Officer in Charge (OIC) of the Behavioural Sciences Branch, Ottawa, Ontario on 13/02/2006 (via internal RCMP email) to obtain a subset of data from the ViCLAS database (Reference number GTO 1930-64). The ViCLAS data was obtained by Melissa Martineau of the HQ Behavioural Sciences Branch, Research & Development Section (date of release 24/03/2006). All aspects of the ViCLAS booklets and database, including the standard questions used are considered Protected "B" by the RCMP and not releasable. Any information provided in relation to a specific case was 'sterilized' by the Behavioural Sciences Branch prior to release to ensure that the victims, suspects or any individual involved with the case, or the case itself could not be recognized or identified.

Permission to access the "E" Division investigation files was applied for using a form RCMP GRC 4026 Research Application and Undertaking. Permission to access the files and utilize any associated information and photographs was granted based on the understanding that no materials would be released which could potentially identify the victim or the specific case. The Form 2026 was approved by Deputy Commissioner B. Busson OIC of “E” Division, Vancouver British Columbia on 08/06/2005.

RCMP form GRC 4026 (Research Application and Undertaking) was used to apply for permission to access the death investigation files stored at HQ archives in Ottawa Ontario. Permission to access the files and utilize any associated information and photographs was granted based on the understanding that no materials would be released which could potentially identify the victim or the specific case. This application was granted by Assistant Commissioner B. Corrigan OIC of PA & CS of Head Quarters, Ottawa, Ontario on 15/08/2008.

Permission to access the Ottawa Police Service (OPS) death investigation files was applied for using a one page research proposal and amended RCMP form 4026 (07/03/2009) as no form existed within the OPS which was designed specifically for that purpose. Permission to access the file information and photographs was agreed to under the same conditions as the RCMP files; that no information or photograph would be included in the dissertation or published material which had the potential to identify the victim or the case. Verbal permission was provided by the OIC of Forensic Identification Services S/Sgt. Kevin Maloney. Access was gained to the records with the assistance of Cst. P. Scharf, Forensic Identification Specialist.

3.2. Materials

The material used for this study includes information taken from death investigation files, which included; investigative and forensic reports (coroner/medical examiner, forensic identification, forensic anthropology, toxicology) and images of the body at the death scene or autopsy. The information mined from the file included the biological profile of the victim, the circumstances of their death and the contributing factors which may have influenced the biological changes to the body during the PMI at the death scene. The information relating to temperature and precipitation for the PMI at the outdoor scenes was calculated using data from the “Canadian National Climate Data and Information Archive”. Although homicide is the most frequent type of manner of death for cases in this study; suicides, accidents and natural deaths are also present.

The homicide cases were selected utilizing information contained in a subset of Violent Crimes Linkage System (ViCLAS) reports; other cases were selected using OPS sudden death reports.

3.2.1. *The Data and Spreadsheet*

A total of 7,328 cases from ViCLAS and the OPS sudden death reports were reviewed and 358 cases selected for the study based on the completeness of data and availability of photographs. A spreadsheet was created using Microsoft office Excel 2007 (Microsoft Office) which included 46 different categories of data for each case. The information consisted of geographical and police file identifiers in addition to 13 environmental, 11 immediate context, 14 scene specific, and 11 intrinsic variables or descriptors. Several of the data categories in the spreadsheet are descriptive, such as type of dwelling for indoor scenes, or type vegetation at outdoor scenes. However, 36 categories of information were assigned a numerical value in relation to an interval or nominal scale, which facilitated ordinary least squares and multiple regression analysis. Interval scales were used to categorize data which had a magnitude of difference between one value and another, e.g., the level of submersion of a body in water was scored in an increasing scale from 1 to 3. Other variables with only two potential categories, such as yes or no, male or female, were assigned a number according to a nominal scale. The data was exported from Excel into Minitab 16 Statistical Software, version 16.2.2.0 (by Minitab Inc) for analysis.

3.3. The Violent Crimes Linkage System (ViCLAS)

Most of the homicide cases used for this study were selected using the ViCLAS database. ViCLAS is an information database which was developed 1991 after several high profile criminals, such as Clifford Olsen and Paul Bernardo highlighted the necessity for the Canadian police community to share information across jurisdictions. The information was used to identify and apprehend serial offenders moving between difference police jurisdictions. The ViCLAS system is based on the American Violent Criminal Apprehension Program (ViCAP) which was developed by the Federal Bureau of Investigation (FBI) in 1985. This program was developed by the FBI in Quantico, Virginia to track serial murders that could be individualized by the signature aspects of their crimes. Criminal profiling resulted in numerous FBI successes in the United States which inspired the development of equivalent ViCAP databases in most developed countries. Today it is possible to track criminals offending internationally using the Interpol I-24/7 network system which can connect to multiple related criminal databases to track murders, paedophiles, and sexual offenders across the 184 member countries.

ViCLAS includes not only homicides, but also sex assaults, abductions, missing persons and found remains where foul play has been suspected. It is the Behavioural Sciences Group (BSG) in the RCMP which manages ViCLAS for all police agencies in Canada. The BSG has specialist technicians to enter the data and search the database for investigators pursuing a specific criminal or crime type. Due to the large numbers of missing persons in British Columbia, the BSG operates a special “Rapid ID Program” which deals exclusively with found human remains. Information related to these cases is analysed by the centralized and networked ViCLAS database in Ottawa to identify the found human remains and subsequently identify any individual or individuals potentially responsible for that death.

The ViCLAS database has been utilized by researchers in the past to develop crime solving strategies such as geographical profiling. Cases from ViCLAS were used to develop GIS based predictive models based on the location of the perpetrator and the physical locations of their crimes (Rossmo 1999). Since 2005, access to ViCLAS for the purposes of research has not been permitted due to privacy and sensitivity issues. As a serving member of the RCMP with top security clearance, an exception was made to this rule for the purposes of this study. The results of this study will be used to enhance and improve on crime scene and investigative methods for all police agencies in Canada. The condition of use for this information was that no details relating to the crime would be released which could identify any persons in any way related to a specific death investigation.

A research technician from the BSG exported a subset of 6,568 homicides cases from the ViCLAS database for the purpose of this study. This ViCLAS report included only solved homicides with known offenders and recovered victims. Each ViCLAS case included 63 separate categories of information relating to the suspect(s), the victim and the circumstances surrounding their death. The information in the ViCLAS report was used to identify cases potentially suitable for the study. The case selection criteria were completeness of data and access to the file to retrieve and review investigative and forensic reports with photographs. The minimal requirement for any case for this study was a known and specific date of death and date of discovery. The establishment of the date of death was based on recorded witness statements or suspect confessions.

There were only four cases in ViCLAS which included digital images of the victim at the scene. For all other cases, the operational police file was obtained to access and evaluate the photographs. The detachment locations and file numbers from ViCLAS were used to obtain the files through RCMP informatics (file management) and centralized archives. Photographs from the recovered files were used to classify the stage of decomposition for the decedent and obtain scene information not available in reports.

3.3.1. ***Police Case Files***

ViCLAS includes cases contributed by all municipal and provincial police forces in addition to the RCMP. Investigational files held by The Ontario Provincial Police (OPP) and the Quebec Sûreté (QS) were not included in the study due to logistical issues. Access to these files would have necessitated a separate series of permissions and travel to each particular OPP or QS detachment due to the lack of a centralized archive or file repository for these two provincial police agencies.

RCMP Case Files

The RCMP files selected from the ViCLAS dataset were requested and retrieved from storage by the file managers. The files were viewed in secure file review rooms at National RCMP HQ, at 1200 Vanier Parkway, Ottawa, Ontario and “E” Division HQ at 5255 Heather Street in Vancouver, British Columbia. The type of Information taken from each file consisted of the circumstances surrounding the death and particulars of the victim and the death scene. The relevant information was input directly into the study spreadsheet in the file review rooms. A digital copy was made of any photographs chosen of the body at the scene or autopsy. The images were captured using a Cannon colour CanoScan 4400F high resolution flatbed scanner for printed photographs. A

Nikon Coolscan V ED negative scanner was used for film negatives and any digital images were copied from the file CD or DVD to an external hard drive. The images were stored on a secure hard drive.   It was not possible to copy any of the photographs of the four cases within ViCLAS. These file images were viewed within the ViCLAS database at ViCLAS head offices Technical Operational Policing Facility (TPOF) in Orleans, Ontario. The level of decomposition was scored based on the photographs at TPOF and immediately entered into the study spread sheet.

Ottawa Police Service Sudden Death Files

A total of 760 OPS sudden death reports were reviewed for potential selection for the study. These deaths had occurred within the jurisdiction of the OPS in the Ottawa region between the periods of 2009-08-10 to 2010-08-10. The files were viewed in the FIS section of the OPS HQ building at 474 Elgin Street, Ottawa Ontario. A total of 167 files were selected from the sudden death reports for use in the study. These cases were selected based on completeness of information and availability of the photographs. These cases included any manner of death, occurring indoors or outdoors throughout the year. The information from the selected cases was entered into the project spreadsheet. The digital images were either downloaded from the Forensic Identification Unit digital image drive, or scanned using the Coolscan negative scanner or the Cannon flatbed scanner. The images were stored on a secure hard drive.

3.4. The Decompositional Classification System

There is considerable variability in the classification systems used by forensic anthropologists to describe the level of decomposition for found human remains. Many of the issues relating to the existing classification systems are that the definitions for the stage of decomposition are relatively broad and poorly defined, e.g., “early decay; advanced decay and skeletonization” (Fitzgerald & Oxenham 2009). Other classification systems have been designed to describe decomposition specific to a certain geographic regions or environment (Galloway et al., 1989), others are so complex, (Megyesi et al., 2005) that classifying the level of decomposition can be a process of best guessing and compromise (Heaton et al., 2009).

The visible appearance of a body during decomposition can be complex and vary according to a range of environmental, immediate context or intrinsic variables. Little is known about the typical progression of decomposition in Canada. As opposed to the adoption and adaptation of another classification system designed for another purpose or geographic region, a new classification system was designed for this study, to describe the range of decomposition occurring in Canada. This classification system was devised to describe the progression of soft tissue as opposed to hard tissue decomposition in Canada. There are two parts to the classification system; a description of the internal baseline biological process of decomposition, and classification of the alternate states of decomposition which can occur due to external environmental variability. There is a certain level of subjectivity associated to the classification of a state based on a range of descriptors. Detailed definitions and illustrative photographs have been provided for each defined stage in this classification system to reduce the conjecture inherent in any non-metric classification system.

Baseline decomposition is a product of the internal biochemical processes of autolysis and putrefaction following somatic death. An imbalance in the external environmental conditions could bring about an alteration in the expected path of baseline decomposition which could result in the preservation or conversion of body tissue. Environmental variability can be caused by variable temperatures, humidity and oxygen levels or increased moisture and acidity levels. Alternate states of decomposition include mummification, moulding on a wet or dry tissue substrate or conversion of adipose tissues into adipocere. An explanation of the conditions surrounding the genesis of these states is provided in Sections 2.4. Categories of alternate states of decomposition have been created in addition to the baseline decomposition system, to quantify the frequency and distribution of these states across Canada.

Table 3.1. Decomposition Scoring Sheet

Baseline Decomposition		Alternate States	
Autolysis		**Mummification**	
No visible changes	**0**	Small portion only	**1**
First visible change: Liver or rigor mortis	**1**	Partial – less than ½	**2**
First tissue change: Hair/skin slippage or epidermal bullae, Marbling of blood in the vein – red colour only Brown/black colour of drying tissue	**2**	More than ½	**3**
		Total	**4**
Putrefaction		**Wet Moulding**	
First colour change (exp. Brown or black) **Blood –** Greenish-Bruises may turn red/brown **Tissue** – Gray - Greenish/Blue or yellow **-** Onset of abdominal swelling	**3**	Fungal growth on wet tissues Small portion only	**5**
Full Bloat - *in combination with…* **Blood** – Deep red to purple **Tissue** – Red (majority)	**4**	Partial - less than 1/2	**6**
		More than 1/2	**7**
Post Bloat **Blood** – Black **Tissue**- Brown to Black	**5**	Total	**8**
Skeletonization		**Dry Moulding**	
First sign of bone : (less than ½ exposed)	**6**	Fungal growth on Dry tissue (red tissue) Small portion only	**9**
More than ½ of bone exposed	**7**	Partial – less than ½	**10**
Total skeletonization: (small fragments of tissue or tendons)	**8**	More than ½	**11**
		Total	**12**

Adipocere

Decomposition Scoring Sheet		
	Transformation of tissue into gray, or white waxy/soap Small portion	**13**
	Partial – less than ½	**14**
	More than ½	**15**
	Total	**16**

3.4.1. *The Stages of Decomposition: Classifiers*

The classification system consists of nine progressive stages of decomposition which represent the advancement of autolysis, putrefaction and skeletonization. Stage 0 is the stage immediately following death and it is characterized by a lack of any visible change. Stages 1 and 2 represent the visible progression of autolysis; and stage 3, 4 and 5 the progression of putrefaction. The last three stages represent the progressive loss of soft tissue and bone exposure. For an explanation of the biological processes involved in decomposition, refer to Sec. 2.4. A one page summary of the classification system has been provided on the preceding page; which is followed by more detailed explanation of the stages of baseline decomposition and presence and extent of alternate states of decomposition.

Stage 0: Fresh State

Stage 0 represents the fresh state of the body after death when there is no visible colour or tissue change to the body.

Stage 1: Early Autolysis – First Visible Colour Change

Stage 1 is the first visible sign of colour changes. This stage is characterized by the red discolouration of lividity. Rigor mortis may be present during this stage but may not be visible until the body has been moved.

- **Liver mortis**: The pooling of blood in the dependant portions of the body. Fixed or non-fixed levity and blanching with contact tissue (Figure 3.1).
- **Rigor mortis**: Stiffening of tissues without any visible deterioration to, or discolouration of the tissue.

Stage 2: Late Autolysis – First Visible Tissue Change

Stage 2 is characterized by the first visible tissue changes due to the advanced processes of autolysis and blood deterioration.

- **Blood**: The bright red colour of blood in areas of lividity, veins or arteries due to the disassociation of oxygen from blood cells results in a dark red to black colour. (Figure 3.3). The subcutaneous blood may become more visible with the increasing pallor of the tissue.

- **Tissue**: 1) Separation of epidermis and dermal layers resulting in skin slippage (Figure 3.1) or epidermal bullae (Figure 3.3) with decreased humidity indoors.
  2) Desiccation of tissues such as digits (Figure 3.2), components of the face or eye balls (*tache noire*) resulting in a black discolouration.
  3) Hair or nail loss

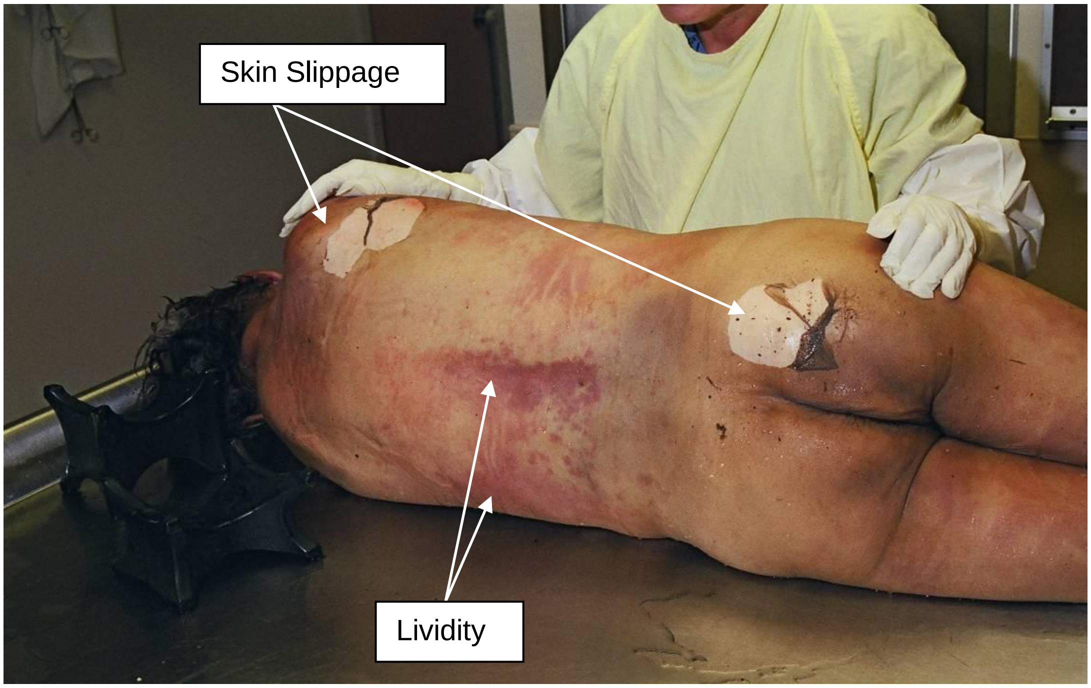


Figure 3.1. Skin slippage and liver mortis

Figure 3.2 Example of blacking of the fingertips due to desiccation

Figure 3.3 Example of epidermal bullae (above jeans) and marbling of the veins and arteries

Stage 3: Putrefaction: Initial Stages

Stage 3 is characterized by the first sign of green, blue or yellow tissue discolouration. The first signs of putrefaction and subsequent colour change are seen in the abdominal area (Figure 3.4). There is no distension of the abdomen at this stage due to the build up of putrefactive gasses. This stage is also characterized the commencement of a green discolouration to any visible blood vessels.

- **Blood** – Green discolouration of visible circulatory system bruising or lividity.
- **Tissue** –Green, blue or yellow discolouration depending on levels of acidity or oxygen.

Figure 3.4. ***The initial stages of putrefaction characterized by a green discolouration of the tissue in the abdominal area.***

Stage 4: Putrefaction - Full Bloat

Stage 4 is characterized by the onset of abdominal distension due to the buildup of putrefaction gasses (Figure 3.5) and the first appearance of red to dark red colour changes to the tissue. Any visible blood may progress from a green to purple discolouration.

- **Blood**: Dark red to green discolouration
- **Tissue**: Onset of red to dark red discolouration. There is full or maximum extent of tissue dissention due to the build of putrefaction gasses.

Figure 3.5. ***Red colouration of the tissue is seen in the area of the upper torso. Blood in the face has a purple colour to it and distension to the tissue is noticeable in the face area.***

Stage 5: Putrefaction: Post Bloat

Stage 5 is characterized by the loss of tissue distension and the transition towards a brown and black discolouration of both blood and tissue (Figure 3.6). A brown colour represents an earlier phase of tissue decomposition compared to the later stages of black putrefaction. This black discolouration is not to be confused with tissue desiccation which can be seen shortly after death due to external low humidity levels. There is a loss of tissue cohesion with the onset of tissue liquefaction.

- **Blood:** brown to black
- **Tissue:** Absence of gasses, or release of gasses with a brown to black discolouration of the tissue.

Figure 3.6. Black and brown discolouration of the tissue with a lack or release of gasses and loss of tissue cohesion.

Stage 6: Onset of Liquefaction & Skeletonization

Stage 6 is characterized by the first exposure of hard tissue due to the colliquation of tissue caused by to autolysis and putrefaction. This stage represents the first exposure of bone exposure due to colliquation. There is no further colour change to the blood or tissue, only an increasing degree of tissue loss.

- **Blood**: Black if visible
- **Tissue**: Black and brown discolouration

Stage 7: Liquefaction & Skeletonization - More than 50% Tissue Loss

This is a proportional estimate of the ratio of tissue loss to bone exposure. If more than half of the skeleton is exposed it is given a score of 7.

Stage 8 - Total Skeletonization

This stage is characterized by almost total colliquation and loss of soft tissue. Only small remnants of tendons and desiccated tissue may be present on the hard tissue.

3.4.2. *Alternate States of Decomposition*

The presence or absence of an alternate state of decomposition was score for each case. An alternate state of decomposition can affect all or specific parts of the body and is generated by an imbalance in the immediate context of that body or part. Alternate states of decomposition are not an expected or normal state of baseline decomposition which occurs under optimal environmental conditions. The alternate states of decomposition are defined as states of tissue preservation or deterioration resulting from the presence of external agents of decomposition (bacteria/fungi) or environmental and contextual variability. A description of the processes and conditions which give rise to these alternate states of decomposition has been provided in the literature review (Sec. 2.4.6.). Definitions have been provided for three types of alternate states of decomposition and the classification system used to quantify the extent of their presence on a body.

Mummification

Mummification of soft tissue occurs when tissue moisture is lost by way of evaporation. Mummification can occur in a dry hot or cold environment. Exposed tissues of the hands and face can be affected by dry conditions and result in mummification. Exposed tissue can mummify while other protected parts of the same body can progress along the normal stages of baseline decomposition. Mummified tissue can stabilize and become resistant to further decomposition due to the absence of moisture. Mummification can restrict the colonization of first instar maggots that lack sufficiently developed mouth parts to consume hardened tissues. Colonization of insects such as dermestid (*dermestidae*) beetles or mature maggots could result in the consumption of desiccated tissues.

Mummification was scored based on the overall extent or proportion of the desiccated tissue.

1 - present on any part of the body (small portion only)
2 - present on less than half the tissue
3 – present on more than half but less than the total tissue
4 – present on almost all tissue

Moulding, Wet & Dry

Wet moulding is the visible presence of fungi or algae on a wet substrate. Tissues have been colonized by an external biological agent of decomposition present in the surrounding scene and made possible by specific environmental conditions. This type of wet moulding was found on individuals outdoors in dark, moist and cool environments.

Figure 3.7. Wet moulding is present on the face of this individual. The substrate is generally wet and these types of algae or fungi manifest in generally cooler, darker environment.

<u>Wet Moulding</u>

5 - present on any part of the body (small portion only)

6 - present on less than half the tissue

7 – present on more than half but less than the total tissue

8 – present on almost all tissue

Dry moulding is the visible presence of fungi on a desiccated substrate. The substrate for this type of moulding is generally a dark red to black colour. It can occur in warm or cold dry environments in indoor and outdoor scene types. Some of the fungal colonies may be the result of endemic fungi present on the tissue during life and propagated after death as a result of favourable environmental conditions (Figure 3.8).

Figure 3.8. A fungal colony on a dry substrate. This fungal colony may be the result of an existing fungal infection during life which was left unchecked in death with favourable environmental conditions.

Dry Moulding

9 - present on any part of the body (small portion only)

10 - present on less than half the tissue

11 – present on more than half but less than the total tissue

12 – present on almost all tissue

Adipocere Formation

Adipocere is defined as a "postmortem chemical alteration of normal adipose tissue rendering it firm, grayish white and of wax-like consistency" (Cotton et al., 1987:1128). Adipocere can be caused by the hydrolysis of triglycerides in adipocere tissue in high moisture, low oxygen environments which may be triggered by the presence of anaerobic bacteria such as *Clostridium perfringens* and *Clostridium figidicanes* (Widya et al., 2012). Depending on the presence of variables such as non-permeable shrouds or clay-based soils, the retention of fluids may give the adipocere a more fluid consistency.

Figure 3.9. ***Adipocere tissue is present in the upper thigh area. The creasing of the pants has left an impression in the adipose tissue.***

Adipocere was scored according to the degree and extent of its presence.

13 - present on any part of the body (small portion only)

14 - present on less than half the tissue

15 – present on more than half but less than the total tissue

16 – present on almost all tissue

3.5. An Inter-Observer Error Study of the Decomposition Classification System

An inter-observer study was undertaken to evaluate the repeatability of this classification system by multiple observers with a range of experience and training. It is proposed to validate the reliability of any new method or classification system with an inter-observer or intra-observer study if appropriate (Grivas & Komar 2008; Christensen & Crowler 2009). The purpose of this inter-observer study was to assess the ability of test subjects to use this system to classify the same or similar stage of decomposition given the same information. I classified the level of decomposition for a test group of 40 photographs. The stage of baseline decomposition and presence and extent of any alternate states of decomposition was scored for each case. Two sets of test subjects used the same classification system to score the level of decomposition for the same 40 photographs. A comparison was made of the results from all three sets of observers.

3.5.1. ***Materials***

A set of 40 cases were selected to represent the full range of stages in the classification system. Only one photograph was provided to portray the level of decomposition for that specific case. The test subjects were provided with a booklet containing these forty test photographs. The colour photographs were 4 ½ x 3 ½ inches in size and arranged four to a page and printed on Kodak Professional © Endura paper. The colour was corrected for all images by the RCMP Forensic Imaging services and the photographs printed at the same time to ensure colour consistency. Each image was identified by a three digit number system starting from 001 and ending in 040 (Appendix A. Part IV). The numbers on the photographs corresponded to numbers (1-40) on the answer sheet.

3.5.2. ***Study Participants***

A test group of 30 police or police affiliated individuals at the Canadian Police College and the RCMP Forensic Identification Operations Support Section (FIOSS), in Ottawa, Ontario were used for this study. The majority of the group (24) were sworn police officers from multiple police agencies. All of the test subjects were either Forensic Identification Apprentices or Specialists with a range of 3 to 32 years service and average of 11.4 years of service. Four other participants were employees of the RCMP who did not have any previous experience with or exposure to decomposed bodies. The test subjects were divided into two groups with an equal representation of police experience in each group.

As part of the inter-observer error study, I completed the process of scoring the stages and states of decomposition for the 40 photographs in test material. These original results were then used as a comparison for the test results produced by the two groups of test subjects. A comparison was conducted to determine the effectiveness of test subjects to replicate my scoring as the experience observer. It should be clear that the test was not conducted to determine the accuracy of the method as there is no ‘right’ answer, only the reliability of the methodology to repeat the results when the same information is provided to the observers. This study involved the comparison of three sets of independent results.

3.5.3. *Instructional Material*

Group 1 was provided with an informational booklet (Appendix A, part I), in addition to a one page summary scoring sheet (Appendix A, part II). Group 2 was provided only the scoring sheet without the information booklet. The instructional booklet consists of a 7 page written document with more detailed explanations and descriptions for the stages and states of decomposition including colour photographs. This additional instructional material was provided to group 1 to determine whether increased explanation and illustrative photographs increased that group's ability to replicate the original results.

3.5.4. *Scoring Sheet*

The scoring sheet (Appendix A, part II) is a two page document in table format which provided a brief summary of the definitions for each of the nine stages of baseline decomposition based on visible colour and tissue changes. Definitions were provided for the extent of each of the alternate state of decomposition without a description of what these states might look like.

3.5.5. *Inter-Observer Error Study Method*

The test subjects were divided into two different groups (group 1 & 2). Both groups were asked to perform the same task; to classify the stage of decomposition for each of the 40 bodies in the photographs. One group (group 1), was provided with an additional instructional booklet to assist with the task of classification. Both groups received the test material photo booklet, two page classification scoring sheet and the answer sheets.

Two hours was provided to complete the exercise, with no discussion or cooperation permitted between the test subjects. Instruction was provided to each group to read the material provided, independently review the photographs, and score the level of baseline decomposition and alternate state of decomposition if appropriate. Each case was assigned a score of 0 to 8 for the baseline decomposition and a score from 1 to 16 for the alternate states of decomposition. In addition to the baseline decomposition score, each case could receive a maximum of two scores for the presence and level of any alternate state decomposition. The results for each case were recorded according to the numbers assigned to each photograph, on the answer sheets provided (Appendix A, part III).

3.5.6. *Analysis*

Two police officers failed to complete the scoring sheets correctly and were removed from the study. The results from the two test groups were compared to the original set of results. The results were analysed using paired *t*-tests and Pearson Correlation analysis.

3.5.7. *Results: Baseline Decomposition*

The results for the collective performance for both groups are provided in Figure 3.10. Group 1 was provided the supplementary instructional booklet.

Group 1 scored the same stage of baseline decomposition for 47% of the cases compared to the stages classified by the original or first observer. Group 2 scored the same level of baseline decomposition compared to the original results, for 44% of the cases. Group 1 classified the stage of decomposition for the cases, to within one stage for 85% of the cases. Group 2 came to within 1 stage of the original stage of decomposition for 82% of the cases. The results in Figure 3.10 suggest that the instructional material provided to group 1 did result in a slightly better ability to replicate the original results compared to group 2.

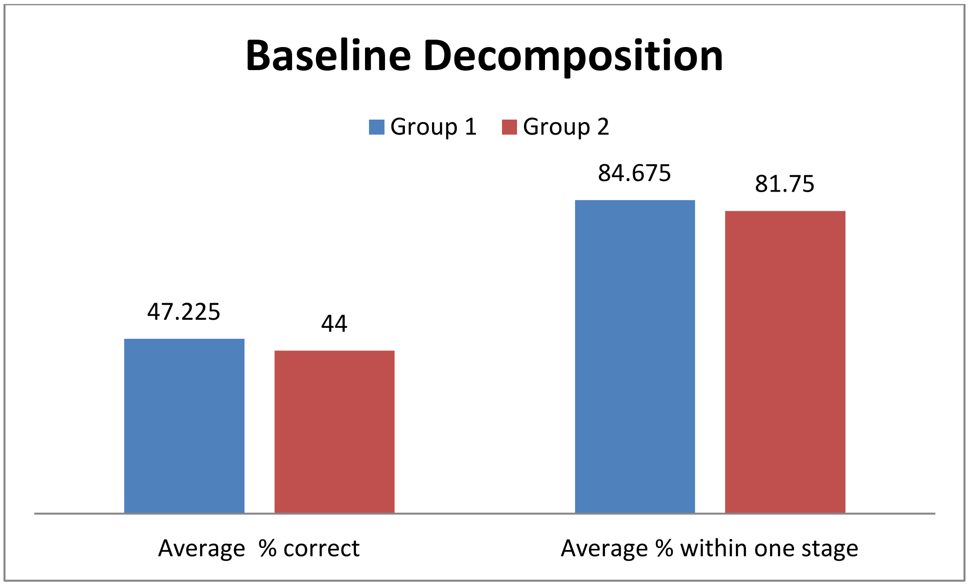


Figure 3.10. ***Comparison between the results of group 1 and group 2 to classify the same stage scored by the original observer for baseline decomposition (left side of the chart). The results for the two groups to classify within one stage of the original stage (right side). In both instances group 1 demonstrated a slightly better ability to score the original stage of decomposition compared to group 2. Group 1 was the group originally provided with the supplementary instructional booklet.***

The results were examined to determine whether there was more difficulty for the two groups to assess the stage of decomposition during the processes of autolysis (stages 1 – 2), putrefaction (stages 3 – 5) or skeletonization (stages 6 – 8). Figure 3.11 displays the mean difference in the results between the two study groups (groups 1 and 2) compared to the results of the original exercise conducted by the author.

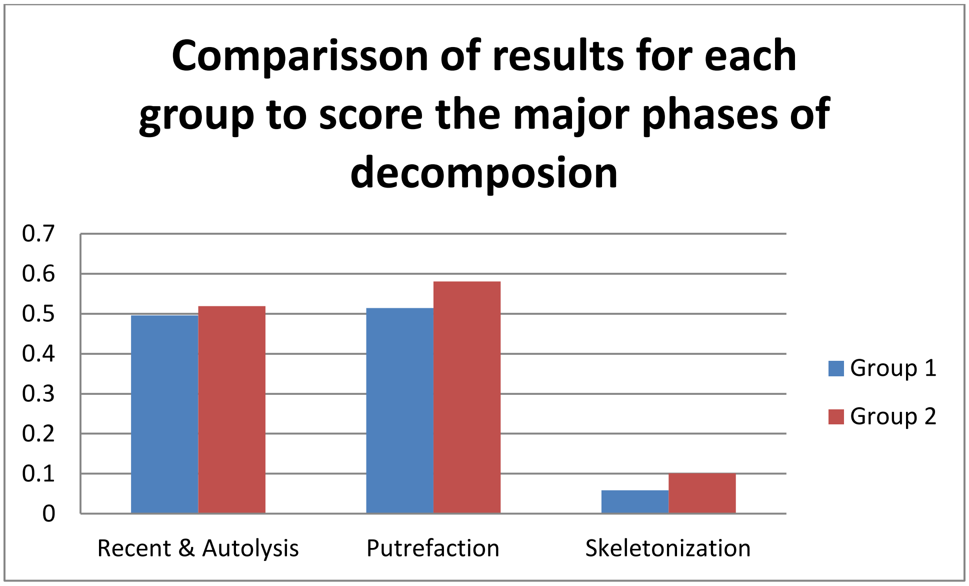


Figure 3.11. ***Comparison of the mean deviation for the two study groups compared to the original results. The results are provided for stages 0 – 2 for autolysis, stages 3 – 5 for putrefaction and 6 – 8 for skeletonization. There is a larger difference in the results for the processes of putrefaction and autolysis compared to skeletonization. The stages of putrefaction appear to be the most problematic to classify. The differences in the results for group 2 are consistently larger than those of group 1. The instructional booklet has assisted group 1 to replicate the original results more reliably than group 2.***

The results suggest that it may be more difficult to assess the stage of decomposition during putrefaction compared to either autolysis or skeletonization (Figure 3.11). The additional explanation has produced in an increased ability for group 1 to replicate the original results compared to Group 2. The significance of the differences in the results between the two test groups was assessed using a *t*-test and Pearson Correlation analysis (Table 3.1). The instructional material did improve the results for group 1, however, the difference between the two groups is not statistically significant (P-value = 0.734).

Table 3.2. Comparison of the Group 1 & 2 to Score Baseline Decomposition.

Paired *t*-test and CI: Group 1, Group 2				
	N	Mean	StDev	SE Mean
Group 1	41	3.497	2.151	0.336
Group 2	41	3.514	2.136	0.334
Difference	41	-0.0180	0.3354	0.0524
95% CI for mean difference: (-0.1238, 0.0879)				
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.34 **P-value = 0.734**				

3.5.8. ***Results - Alternate Decomposition***

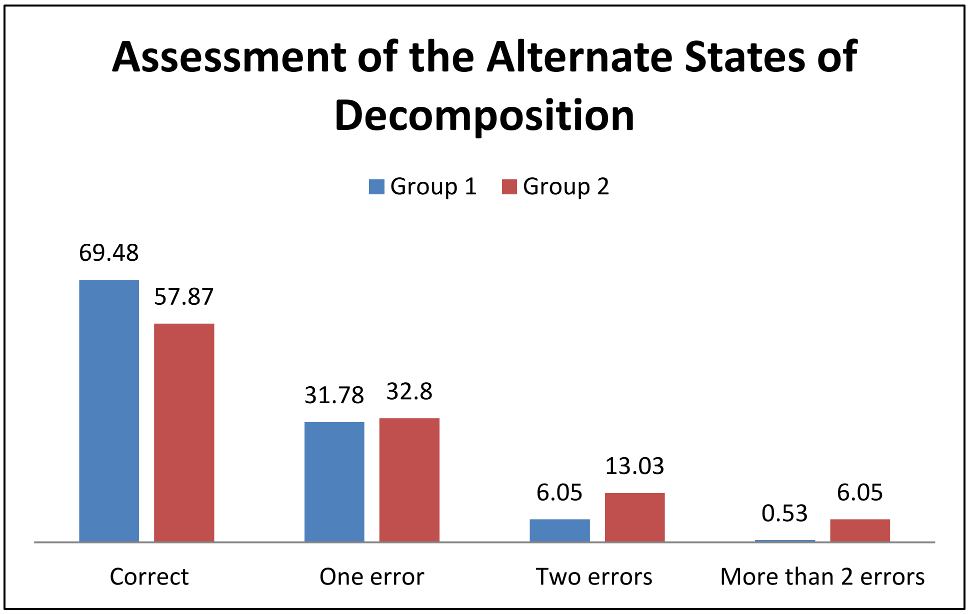


Figure 3.12. Comparison of the two study groups to recognize and classify the alternate state of decomposition. With the additional instructional material, group 1 was more successful in replicating the original results of the study compared to group 2. Both groups were within one score of the original score, for approximately 32% of the cases.

The impact of additional explanation with photographs was evaluated to determine whether this produced an enhanced reinforcement to recognize and define alternate states of decomposition. Information and classifiers were provided for four alternate states of decomposition: mummification; dry moulding; wet moulding and adipocere formation. The results do show an increased ability of group 1, compared to group 2 to recognize the presence of alternate states of decomposition. Group 1 classified the same alternate stage of decomposition, compared to the original results, for 69% of the cases compared to group 2 who correctly scored only 58% of the cases (Figure 3.12). Group 1 deviated less often from the original score compared to group 2.

3.5.9. *Discussion*

The purpose of this inter-observer error study was to determine whether there was sufficient explanation or clarification provided with this classification system to enable multiple users to classify the same or similar stage of decomposition given the same photographs. The disparity in the results of all three observers confirmed that there is a level of subjectivity in the classification system. The impact of additional explanation and visual aids suggests that more clarification and perhaps further experience may increase the ability of observers to achieve similar results.

Both groups were able to replicate the original results of the study to within one stage of baseline decomposition (82 & 85%) and alternate states (66 & 67%) of decomposition for the majority of the cases. The increased ability of group 1 to replicate the original results more reliably demonstrates the benefit of more detailed explanation. The results also suggest that the classification system can be used successfully with relatively limited explanation and no previous experience. Based on the results of the inter-observer study, it was determined that no modifications were needed for the classification system; as the arbitrary categories defined by the classification system could be recognized and replicated by experienced and non-experienced users with a range of explanation and instruction.

3.6. The methodology to answer the four main aims of the study

There are four main aims of this project. The first aim is to establish the baseline progression of decomposition and determine the presence and extent of the alternate states of decomposition indoors, outdoors, in burials and in water. The second and third aims are to identify which variables impact the progression of decomposition in the four scene types and determine whether the geographical location of a scene can result in variability of decomposition and alternate states of decomposition in Canada. The last aim of the study is to evaluate the 'Universal formulas' (Vass 2011) to estimate PMIs and the potential for PMI estimation within the Canadian dataset.

3.6.1. ***Part 1, Q1: The Baseline Progression of Decomposition by Scene Type and the Occurrence and Extent of Alternate States of Decomposition in Canada***

The first part of the study involves the quantitative and qualitative examination of the variability of human decomposition within the Canadian dataset. The three specific aims of this section of the study are:

1. What is the normal progression [normal decomposition is hereby defined as: the most common or frequent set of visible diagnostic traits exhibited by a body at that stage of biological decomposition within a specific context] of human decomposition in Canada?
2. Is there a qualitative or quantitative difference in the progression of decomposition occurring outside, inside, buried or in water?
3. What is the frequency and distribution of alternate states of decomposition such as mummification, moulding and adipocere formation at each scene type across Canada?

3.6.2. ***The Normal Progression of Human Decomposition in Canada***

The baseline decomposition was scored for each case using the classification system based on case photographs from the scene or autopsy. Baseline decomposition is defined as the biological progression of human decomposition given an optimal environmental context (no development of alternate states of decomposition). A maximum of two scores was provided for the presence and extent of an alternate state of decomposition visible in the case photographs (Table 3.1). This decomposition score was used to construct a progression of decomposition for the all cases in the outside, inside, burial and water datasets based on the accumulation of time (PMI in days) and temperature (ADD score)

The two main dependant variables used to quantify the relative progression of decomposition is the accumulation of time (PMI) and temperature (ADD score). There are studies which have used weight loss to describe the progression of decomposition for test subjects; however this method is only appropriate for experimental studies. The following is a description of the methods used to calculate the ADD scores and PMI in days for each case in this study.

The Calculation of the ADD Score

The Accumulated Degree-days (ADD) score was calculated by adding all positive mean daily temperatures that the body was exposed to for the duration of the PMI. The ADD score calculation was based on the method described by Megyesi et al. (2005). The environmental data used to calculate the ADD score was taken from the *Canadian National Climate Data and Information Archive* which was available on the internet (http://climate.weatheroffice.gc.ca/climateData/canada_e.html). The data used to calculate the ADD score was taken from the geographically closest weather station.

The ADD score is defined as:

> <u>ADD Score</u>: This is the accumulation of average daily temperatures recorded (from the nearest weather station) for the period of the PMI. Only positive temperatures were added to the ADD score. The ADD score has been calculated using temperatures recorded at the geographically closest weather station. This data was accessed using the on-line web based *Canadian National Climate Data and Information Archive.* The temperatures for the indoor cases were calculated using an arbitrary mean 20˚C for each PMI day.

Based on the methodology described by Megyesi et al. (2005), only positive temperatures were used for the calculation (all negative temperatures were excluded) for outdoor scenes or scenes under shelter without heating such as outdoor garages or sheds. Megyesi et al., 2005 used the outdoor mean temperature to calculate the ADD score for indoor scenes. Due to the potential temperature differential between outdoor and indoor temperatures for temperature controlled structures in Canada, an arbitrary amount of 20˚C was used to calculate the ADD score indoors. For cases with a PMI exceeding 30 days, the ADD score was calculated for the first 30 days in addition to the entire PMI.

The progress of each increasing stage of decomposition has been presented in an interval plot format using the mean ADD score with an associated 95% confidence interval. The confidence errors have been included with the mean ADD score calculations to comply with the standards of forensic science as defined by Daubert (No. 92-102 506 US 579, 1993) and Mohan (R v. Mohan [1994]:25). The mean ADD scores have been used to provide a general trend in accumulated temperature for a body to progress through the stages of decomposition given a specific context.

3.6.3. *The Calculation of PMI in Days*

Only cases with known and specific PMIs were used for this study. Even if the hour of death was known, the PMI was provided in days. The PMI for each case was calculated based on police witness or suspect statements. No other PMI estimation method was used to determine the date of death. The impact of seasonal variability on the progression decomposition was investigated using the month of the individuals death and discovery. The PMI was considered a maximum score as crime scene examination (including photographs) can take a period of time after the discovery of the body.

The variables in the dataset used to calculate the PMI in days as well as the variable of seasonality relating to the PMI are defined as:

Date Missing: The actual date that the person died. This is either the last time the person was seen alive, or the date of death based on witness or suspect statements.

Date Discovered: This is the date that the body was discovered and photographed by investigators.

PMI in days: The PMI in days score is the amount of time which has passed in days between the date of death and the date the body was discovered. The PMI is considered to be a maximum amount of time.

Month Missing: The month that the victim went missing. The months are scored from 1 (January) to 12 (December).

Month Located: The month that the victim was discovered and photographed by death investigators. The months are scored from 1 (January) to 12 (December).

The mean PMI days was calculated for each stage of decomposition with an associated 95% confidence interval in and presented in an interval plot format. The interval plots were used to demonstrate the progression of decomposition in units of PMI days. These interval plots have been used to illustrate the differences in the accumulated time and temperature it takes a body to progress through each stage of baseline decomposition.

3.6.4. *Part 1, Q2: Is there a Qualitative or Quantitative Difference in the Progression of Decomposition occurring Outside, Inside, Buried or in Water?*

There is a countless variety of environments in which a person can die or be deposited. Homicide, suicide or accident victims have been found suspended in the air, embedded in concrete, or frozen in glaciers. However, the four most common contexts are: inside in a dwelling, outside on the surface, in a burial and in water. The deposition of a homicide victim in a grave is relatively rare in Canada; there are only 22 buried cases in this dataset. There has been a considerable amount of research committed to the investigation of the burial environment and its impact on decomposition (refer to sections 5.1.4.1 to 3). There are 27 cases in this dataset where the bodies have been found in water. The water cases have been separated from both indoor and the outdoor dataset to form a separate scene type.

The variable of scene type is described as:

Scene: The type of scene: 1 - Indoors, 2 – Outdoors or 3 - Water. The buried scene is a subset of the outdoor scene types.

A hanging or suspended individual was classified as either inside or outside according to their location. Any individual located in a dwelling which was not contained and exposed to the outside temperatures (such as an open unheated garage or cabin) was included in the outside classification. Decedents found in a water context (which includes bathtubs) were primarily classified as water cases either inside or outside.

The dataset was divided by the four different types of scene: inside, outside on the surface, burials and water. The mean ADD score and PMI in days with an associated 95% confidence interval were calculated for each stage of baseline decomposition for each subset of cases. Due to the negative impact on averaging calculations, the cases with long PMIs (exceeding 1 year) were been removed from the calculation. The sample sizes for the outdoor and indoor scene types were relatively large (Outside 121 and Inside 193 cases), compared to the smaller samples sizes for the buried and water scenes of 27 and 22 cases respectively. Due to the small sample sizes for the burial and water scene types, caution must be used to evaluate the mean PMI and ADD scores provided for each stages of decomposition.

The progression of decomposition for all scene types was compared to determine if a particular stage or set of stages took more or less time or temperature for one scene type compared to another. Time-line graphs were used to illustrate the variability in the progression of decomposition within and between each stage of decomposition by scene type. A subjective assessment was conducted using the case photographs to identify any visible commonalities that could be used to identify decomposition within a specific scene type.

3.6.5. ***Part 1, Q3: What is The Frequency and Distribution of Alternate States of Decomposition such as Mummification, Moulding and Adipocere Formation at each Scene Type across Canada?***

Alternate states of decomposition occur when there is an environmental imbalance in the immediate context of the body. The environmental variables which might trigger alternate states of decomposition include (but are not limited to); extremes of humidity, temperature, or available oxygen. The alternate states of decomposition examined during this study including mummification, wet or dry moulding and adipocere formation. The alternate states of decomposition have been defined and described in Section 3.5. As the result of body position, coverings or context, bodies have been observed to have a complex of multiple alternate states of decomposition such as mummification, dry moulding and adipocere formation. The presence and extent of a maximum of two alternate states of decomposition was scored for each case. The primary state is the state with the highest level of prevalence. Therefore a body could have a score for mummification in a range of 1 to 4, in addition to another state such as moulding (score of 5 to 12) or adipocere (score of 13 to 16). The presence of alternate states of decomposition was evaluated and scored contemporaneously with the baseline decomposition score.

The frequency of each alternate state of decomposition was established and the distribution mapped within Canada using GIS. The distribution maps were used to determine whether any alternate state of decomposition was geographically or ecologically limited. The timing of the appearance of each alternate state of decomposition (scored from 1 to 16) was determined by calculating the mean PMI in days for the set of case with that alternate decomposition score. The average time and temperature it took to achieve a specific level of mummification, adipocere formation or moulding was provided using PMI in days and ADD scores. Box and interval plots with confidence intervals of 95% were used to illustrate the variability in the time and temperature for the progression of alternate states of decomposition by scene type. To determine the optimal conditions for the genesis of specific types of alternate states of decomposition, comparisons were made between the frequency and extent of mummification for inside versus outside cases and for adipocere formation in water versus buried cases. These results have been presented using variety of tables, box charts or histograms.

3.7. Part II: The Variables Which Affect Decomposition in Canada

The aim of this part of the study is to determine which variables affect the progression and state of decomposition in Canada. The three specific aims of part II of this study are:

1. Which of the two independent variables of accumulated time (PMI) or temperature (ADD score) has a more significant impact on the variability in the decomposition score in Canada?
2. Which independent variables have an impact on the variability of decomposition inside, outside, in burial or in water?
3. What complex of variables contributes to the variability in the decomposition score in the four scene types: inside, outside, burial or water?

The variables affecting decomposition can be organized into several categories: progression (time & temperature), environmental, immediate context, and intrinsic variables. The variables of time and temperature will be examined to determine which one has a more significant impact on the progression of decomposition. The variables have then been examined individually, and then as a complex for each scene type.

3.7.1. ***Part II, Q1: Which of the Two Independent Variables of Accumulated Time (PMI) or Temperature (ADD Score) has a more Significant Impact on the Variability in the Decomposition Score in Canada?***

In recent years, the ADD score has replaced the PMI (in days) as the predictive variable for decomposition (Fitzgerald & Oxenham 2009, Simmons et al. 2009, Heaton et al. 2009, Bachmann et al. 2010 and Vass 2011). The predictive value of both the ADD score and the PMI in days was measured to determine which variable contributed to the largest amount of change in the decomposition score for the cases in this dataset. Although the same method was used to calculate the ADD score as defined by Megyesi et al. (2005), the Total Body Scoring (TBS) classification system used in that study was not utilized in this study. The TBS was designed to describe *typical* decomposition in the United States and was based on the assumption that the progression of decomposition was visible on all body parts simultaneously. The decomposition classification system used for this study was based on *typical* decomposition in Canada, and was based on the assumption that putrefaction originates in the lower intestine and disseminates throughout the body from that point. The decomposition classification system created for this study is a numerically progressive classification system similar to the one used by Megyesi et al. (2005). The study by Megyesi et al. (2005) found a high level (85%) of correlation between the ADD score and the progression of decomposition. The aim of this study is to determine whether the ADD scores could be used as the principle predictive variable to explain the majority of the change in the decomposition scores for Canadian cases.

Simple least square regression analysis was used to quantify the amount change in the decomposition score contributed by the variability in the ADD score or PMI in days. The regression analysis results have been provided in scatter plot format with the regression line and relevant R^2 %. The higher the correlation percentage, the more the change in one variable explains the change in the other. The Normal Probability, Versus fit, Histogram of residuals and Versus Order plots were evaluated for the regression results for the ADD score and PMI days versus the decomposition score. Linear regression was utilized based on the assumption that the regression model was linear in the coefficients. The standard error of regression was evaluated for the regression analysis of both PMI and ADD scores. Regression analysis of the ADD score versus the PMI in days was conducted for the different scene types as well as different time periods from one year, to 31 days, with and without the outliers removed. The sample size for this analysis was a maximum of n=341 compared to n=66 in the study by Megyesi et al. (2005).

A comparison was made between the results of this study and the results achieved by Megyesi et al. (2005). Megyesi et al. (2005) made the assumption that the relationship between the ADD score and the decomposition score was not linear and conducted a transformation of the data using log10 to straighten the curve. Curve straightening is used to investigate the correlation between two variables with a non-linear relationship. A similar transformation of the data was conducted for cases in this study using the fitted line plot and log10 of the Y analysis with a confidence level of 95.0. The Log10 transformation was conducted to replicate the methods used by Megyesi et al. (2005) and determine if that would produce improved correlation results compared to the simple least squares regression results.

3.7.2. *Part II, Q2: Which Independent Variables have an Impact on the Variability of Decomposition occurring Inside, Outside, in Burial or in Water?*

This study has identified a number of environmental, immediate context and intrinsic variables which may have an impact on decomposition. These variables were assessed to identify which variables or complex of variables was responsible for the greatest impact on the progression of decomposition indoor, outdoor, buried, and in water. The variables examined for this part of the study were grouped into three larger sets of environmental, immediate context and intrinsic variables.

For the evaluation of the environmental, immediate context and intrinsic variables it was not possible to produce a time or temperature progression of decomposition (mean ADD Scores/PMI in days by stages) to represent all independent variables, as multiple variables affect a single case simultaneously. To evaluate the impact a variable might have on the relative rate of decomposition, a value index was created for each case called the Relative Level of Decomposition value (RLDV). This index was designed to express how average or unusual a specific case was compared to other cases at that stage of decomposition for that scene type. The index was created with the intention of identify anomalous cases which would in turn identify the variable or set of variables responsible for the anomalous progression of decomposition. The mean RLDV was calculated for the set of cases with or without a variable to assess whether this presence or absence resulted in a faster or slower rate of decomposition.

The Calculation of the Relative Level of Decomposition Value (RLDV)

The ADD score was used to calculate the RLDV. The mean ADD score was calculated for each stages of decomposition by scene type. The RLDV is the standard deviation from the mean which represents how much above or below the norm that specific case is. The RLDV was presented as either a positive or negative number. The positive numbers are the number of standard deviations above the norm, which implies that it took more temperature than average to achieve that stage of decomposition. The cases with a negative RLDV imply that that case took less temperature to achieve that stage of decomposition, and potentially achieving that stage sooner than other cases at that stage of decomposition for that scene type.

The mean ADD score and associated standard deviations were calculated for each of the nine stages of decomposition in the four scene types. Due to the negative impact of very large ADD scores, the cases with a PMI of more than 1 year PMI were removed from this calculation. The majority of the cases fell within 2 standard deviations of the mean. A RLDV of -2 indicates that the ADD score for that case is 2 standard deviations lower (faster) than the mean. The frequency and distribution of RLDV was examined to determine if anomalously high or low RLDVs could be associated to the presence, absence or variability in a specific variable.

Environmental Variables

The environmental data used for this study was taken from the *Canadian National Climate Data and Information Archive* (http://climate.weatheroffice.gc.ca/climateData/canada_e.html). The environmental data for each case was taken from the geographically closest weather station. The impact of the accumulation of precipitation and exposure to cold and freezing temperatures has been examined to determine the impact of these two variables on the progression of autolysis and putrefaction. The accumulation of temperature is an environmental variable; however, due to its importance as a principle predictive variable of decomposition it has been discussed separately (section 3.7.1).

There are multiple researchers who believe that humidity and moisture make a significant contribution to the progression of decomposition (Table 2.7). Humidity levels can range dramatically across Canada both indoors and outdoors according to the season. The average humidity level for homes in Canada can range by season based on the use of heating or cooling systems in the summer and winter months. The relative humidity for the lower-mainland area of British Columbia is on average over 70% throughout the year however, for Ottawa, Ontario it is over 75% (http://ottawa.weatherstats.ca/metrics/relative_humidity.html accessed 2012-03-08). The recommended humidity level in Canada for residences during the winter is between 30 to 50 percent (Canada Mortgage and Housing Corporation website accessed 2012-03-08). Humidity levels can vary from inside to outside scenes from one season to the next. The level of humidity can also be affected by the geographical location of the scene with latitude, prevalent weather patterns and proximity to the Great Lakes affecting humidity levels during specific seasons.

Unfortunately, the humidity level is not a value which is routinely recorded at death scenes. The level of humidity at an indoor death scene cannot be estimated based on retrospective data mining from police files or daily environmental records. It may be possible to estimate the level of humidity at outdoor scenes in very general terms based on the amount of accumulated precipitation. Another source of information which may relate to relative humidity at a scene is an assessment of the extent of visible water at the time of scene attendance. The presence or absence of visible water at the scene is of course generally dependant on precipitation.

The data recorded in the spreadsheet that was used to assess the impact of environmental variables on the progression of decomposition included:

Total Precipitation: This is the cumulative amount of precipitation during the post mortem period. Precipitation included snow as well as rain. The amounts were calculated based on data from the nearest weather station using the "Canadian National Climate Data and Information Archive".

Maximum Temperature: This is the highest temperature recorded during the post mortem interval.

Minimum Temperature: This is the lowest temperature recorded during the post mortem interval.

Average Temperature: This is the average of all hourly temperatures measured for that 24 hour period.

The impact of precipitation was examined as an independent variable using ordinary least squares regression analysis to determine whether an increase in precipitation levels contributed to an increase in the stage of decomposition. The minimum and maximum temperatures were examined using regression analysis to determine whether there was a correlation between the minimum and maximum temperatures and the stage of decomposition. The impact of cold temperatures on the progression of decomposition was examined by removing a sub-set of cases which had been exposed to temperatures of 4˚ C or less during their PMI. The progression of decomposition for these 'cold' cases was compared to the progression of decomposition for the rest of the outdoor group.

Immediate Context Variables

The immediate context variables consist of all variables in the immediate area of the body at the scene which could impact the progression of decomposition. The immediate context variables include the material which surrounds the body (water, soil, clothing or shrouds), the surface upon which they rest and exposure to other variables such as sun, insects and scavengers. The data for each one of these variables was taken from information contained in the file or through evaluation of the photographs from the scene and autopsy. The presence or absence of a variable was scored if it was visible in the photographs or recorded in the reports. For any variable where the information was unavailable, the variable was recorded as "unknown".

Scene Context

The scene context consists of all variables which are specific to the environment or conditions of that scene. These variables may vary between one scene and another in the same geographic or ecological region (ecozone).Several variables were used to evaluate the impact of context variability. Many of these variables are descriptive as opposed to values on an interval or nominal scale.

The variables in the spreadsheet for this component of the study are defined as:

Structure: The type of constructed structure: 1 – enclosed (not open to the environment) or, 2 – not enclosed (exposed to the outdoor temperatures, precipitation, flora and fauna).

Outdoor Qualifier: Scored by type of setting: 1 - Urban or 2 – Rural

Urban: Urban scenes were further subdivided into ten different types: 1 – road/parking, 2 – Backyard/lot, 3 – vehicle, 5 - Landfill, 6 – Other, 7 – Ditch, 8 – Residence, 9 – Hotel room, 10 – Trailer, 0 - Other.

Rural: Divided into: 1 – land, 2 – Water.

Water: When the body was found at least partially submerged in water it was divided into three types of water: 1 – salt, 2 – fresh, 3 – sewer.

Fresh water: Subdivided into either: 1 – flowing, 2 – stagnant.

Submersion: At the time the body was recovered, the level of submersion for the body was either: 1 – partial, 2 – moderate (approximately half the body mass), 3 – total.

Surface/Buried: The location of the body outside: 1 – surface, 2 – shallow grave (some portion of the body was visible), 3 – deeply buried (the body was buried entirely under the surface.

Land 2: The type of surface environment: 1 – wooded, 2 – grasslands, 3 – mixed, 4 – farmed, 5 – pine forest, 6 – brush/bushes, 7 – tarmac, 8 – snow, 9 – Other.

Terrain: The slope of the site: 1 – flat, 2 – sloped, 3 – concave.

Surface Type: The quality of the surface type: 1 – reflective (i.e., light coloured stone or sand), 2 – Absorbent (mineral), 3 – organic (i.e., leaf matt, soil).

Shaded: The amount of sunlight that the body was exposed to during the post mortem period: 1 – Shaded, 2 – Partial, 3 – Full Sun.

The descriptive variables such as type of structure, outdoor qualifier, urban, rural, land 2, terrain and surface type were assessed in combination with other variables using the RLDV for a specific stage or processes of decomposition. The other interval scale variables such as level of submersion in water, depth of burial and extent of shade were evaluated with regression analysis to evaluate their contribution to the progression of decomposition. The variability in the progression of decomposition was examined for variables such as extent of sunlight or burial versus surface using interval plots of mean ADD scores or PMI in days.

Exposure of the body and impact of scavengers

These variables examined the impact that the extent of clothing and coverings had on the rate of decomposition in various scene types. The influence of scavenging, and insect involvement was also examined to determine if they contributed to the acceleration or deceleration of the rate of decomposition outdoors.

The following is a list of the variables used to evaluate the impact of immediate context variables:

Body Disposal: The placement or staging of the body based on ViCLAS records and scene photographs: 1 – not hidden, 2 – hidden, 3 – staged scene.

Position of Body: The orientation of the body at the scene: 1 – face down, 2 – face up, 3 – foetal position, 4 – recovery position, 5 – sitting, 6 – hanging, 7 – other, 8 – scattered.

Clothing: The presence and extent of clothing that the victim was wearing at the time of discovery: 1 – fully clothed, 2 – exposed genitals, 3 – partial, 4 – naked.

Shroud: The presence and type covering or wrapping of the body: 1 – none, 2 – breathable (bedclothes or sleeping bags), 3 – mixed, 4 – non-breathable (plastic).

Objects on Body: The presence of objects or debris placed on top of the body: 1 – rocks, 2 – wood, 3 – mixed debris, 4 – mixed.

Scavenging: The visible impact of scavenging (of any type of scavenger): 0 – none, 1 – minimal (small amount), 2 – moderate (less than half the tissue), 3 – extreme (more than half the tissue).

Insects: The visible presence of insects (of any kind): 0 – none, 1 – ovipositing (laying of eggs), 2 – minimal maggots, 3 – moderate, 4 – extreme (full maggot mass).

The type of body disposal and position of the body are descriptive variables, however the other variables in this group were quantified according to an interval scale and assessed using ordinary lease square regression analysis. Regression analysis was conducted to determine the contribution of each variable to the negative or positive impact on the progression of decomposition. Pearson correlation analysis was used to compare the results of the presence or absence of a variable such as clothing or shrouds. Paired *t*-tests were also used to evaluate the significance of the differences in the decompositional sequences between the presence and absence of the same variable.

Intrinsic Variables

The intrinsic variables are those variables specific to that individual. These variables may relate to the biological profile of the person, such as their age, sex, build, health or manner of death. The impact of the consumption of alcohol or drugs and the extent of blood loss on the progression of decomposition was also examined.

The following is a list of intrinsic variables with associated definition:

<u>Sex</u>: Two biological classifications of either: 1 – Male, 2 – Female.

<u>Age</u>: The actual age of the victim in years at the time of death. For an infant under the age of 1 year old, the individual received a score of zero.

<u>Facial Appearance</u>: The population group of the individual assigned by either ViCLAS or police records using their terminology: 1 – Caucasian, 2 – Black, 3 – Aboriginal, 4 – Oriental, 5 – East Indian, 6 – Hispanic, 7 – Middle Eastern, 8 – Other.

<u>Height</u>: The recorded living height of the individual if provided.

<u>Weight</u>: The recorded living weight of the individual if provided.

<u>Build</u>: The estimated size range of the individual based on body mass: 1 – small, 2 – Average/Medium, 3 – Large, 4 – Obese. Most assessments were based on police records, others estimated based on photographs from the scene and or autopsy.

<u>Illness/Disease</u>: The presence of a recorded disease or illness at the time of their death: 1 – No, 2 – Yes, 3 – Unknown. Depression and mental illness were scored as positive (2).

Manner of Death: The manner of death as determined by the Coroner, Forensic Pathologist or Medical Examiner: 1 – Homicide, 2 – Natural death, 3 – Suicide, 4 – Accidental, 5 – Indeterminate.

Type of Trauma: The type of trauma which may or may not have caused their death: 1 – Ballistic, 2 – Sharp, 3 – Blunt, 4 – strangulation, 5 – Drowning, 6 – Suffocation, 7 – Other.

Number of Blows: The actual number of blows (if any) recorded by the pathologist, or the total number of trauma sites visible in the photographs.

Area of trauma: The general area of the body where majority of trauma was focused. This was provided in the comments section.

Blood loss: The volume of blood lost by the victim, based on the scene assessment and pathology reports: 1 – Minor, 2 – Moderate, 3 – Extreme, 4 – Total (exsanguination).

Drugs: The consumption of drugs prior to death: 0 – unknown, 1 – No, 2 – prescription, 3 – illicit or non-prescription. If prescription drugs were recorded at the scene – the specific types were recorded in the comments field.

Non-Prescription Drugs: The consumption of non-prescription drugs prior to death: 1 – Cocaine, 2 – Heroine, 3 – Crystal Meth, 4 – Other.

Alcohol: The consumption of alcohol prior to death: 1 – No, 2 – Yes and 3 – Unknown.

Many of the intrinsic variables recorded for this study were descriptive and could not be quantified with an interval scale. The variables that were quantified with an interval scale included: age, build and blood loss. Other variables such as alcohol, drugs, illness and sex were examined using a nominal scale or presence or absence. Interval pots were used to display the time or temperature progression of decomposition for one state of the variable compared to another; e.g., the mean time it takes the set of cases with alcohol consumption to achieve stage 1 decomposition compared to the set without. Basic statistical methods such as a paired *t*-test were used to compare the results from one group to another to determine if the differences were statistically significant. Pearson Correlation analysis was also conducted to determine the correlation of the results. Other variables with a range of non-quantifiable states such as manner or death were evaluated as they related to other variables such as extent of blood loss or RLDV.

Frequency & Distribution of RLDV for Independent Variables Using GIS

A series of spatial analysis were conducted for a number of independent variables in this study. ArcGIS 9.3 Geographic Information System (GIS) software (Estri®) was used to geocode the location of each case to the nearest town and mapped on Canadian political (by province & territory) or ecozone maps using Adobe® Illustrator® CS6 Software.

Table 3.3.   GIS maps for independent variables affecting decomposition

Map Figure	Variables examined	Data source for each variable
Figure 4.71	Distribution of cases with and without **Insect Involvement** & **Scavenging** Frequency of Insects & scavenger cases for indoor & outdoor scene types	Information taken from case crime scene & autopsy photographs
Figure 4.90	Distribution of RLDV by **Sex** (male and female) Frequency of RLDV by sex	Information taken from case records
Figure 4.95	Distribution of RLDV by **Build** (small, normal, large, Obese)	Information taken from crime scene & autopsy photographs and case records
Figure 4.109	Distribution of RLDV for all cases. Frequency of RLDV by **Age**, **Sex**, **Alcohol** consumption and **Manner of Death**	Information taken from case records, including toxicology reports.

GIS was used to present cartography, spreadsheet and statistical analysis data relating to groups of cases with or without a specific variable.   The GIS maps were used to assess whether the relative rate of decomposition relating to these variables could be associated with geographical or environmental patterns. The distribution of the presence or absence of a variable (Figure 4.71), and the distribution the RLDV for cases with or without a specific variable (Figures 4.90, 4.95 & 4.109) were mapped. The methodology used to calculate the RLDV for each case has been described in Section 3.7.2.1. The geographical location for each case was taken from the police files.

3.7.3. *Part II, Q3: What Complex of Variables Contributes to the Variability in the Decomposition Score in the Four Scene Types: Inside, Outside, Burial or Water?*

General and stepwise regression was used to evaluate the contribution of multiple variables to the progression of decomposition. To determine whether the range of contributing variables varied by scene type multiple regression analysis was conducted for each set of cases by scene type. Multiple regression analysis was conducted for each set of environmental, immediate context and intrinsic variables to identify the significant variables within that group of variables. Forward and backward stepwise regression was used to remove variables which had a significance score of less than P-value=0.15 (alpha to remove or enter in the step-wise process). The automated selection process was used to objectively create a model with the highest R-value. Specific predictors were not kept in the model regardless of their P-values. Variables were included in the model if they had an overall positive contribution to the models' R-value regardless of their specific P-value. The residual plots were used to evaluate the lack of fit, distribution, and linear orientation of residuals to ensure that the predictors were uncorrelated with the residuals. The multicolinearity of these sets of variables was evaluated using a correlation matrix. The only two variables with multicolinearity were the PMI days and ADD scores. Therefore, these two variables were not input into the general regression analysis together.

The smaller group of significant variables identified for each set of variables were then used in for the final regression analysis for each scene type. This staged approach to multiple regression analysis was conducted to reduce the amount of separate variables in the analysis which would have decreased the regression results due to the adjustment that the process makes for each variable being evaluated. The multiple regression analysis provided a list of significant and contributing variables which could be collectively attributed to a specific percentage of change in the decomposition score for each scene type. Multiple regression analysis was also conducted to identify the variables contributing to the progression of decomposition regardless of scene type.

3.8. Part III: Determine whether there is a Geographical Variability in Decomposition in Canada

The aim of this part of the study was to determine whether or not there was a regional or ecological variability in the pattern or rate of decomposition in Canada. The two specific aims of this section were to determine whether there was variability in decomposition based on ecozones and geographical distribution, and whether alternate states of decomposition could be associated to a specific region or ecozone.

3.8.1. *Part III, Q1: Is There a Quantifiable Difference in the Time or Temperature Progression of Decomposition between two Ecozones of Canada?*

Global Information System (GIS) software was used to examine the variability in baseline decomposition based on geographical location within Canada. The location of each case was geocoded to the town level using Google maps. The maps were created using ArcGIS 9.3 software and Illustrator. The specific physical location of the case was taken from the police files and converted into location on a map and assigned a ecodistrict and ecozone value. Each case was assigned to a specific ecozone and ecodistrict using the on-line Agri-Environmental Services Branch *National Ecological Framework for Canada* (http://nlwis-snitel.agr.gc.ca/eco/index.phtml#). The framework was designed to provide a consistent context to describe ecosystems as ecological units. There are 15 main terrestrial ecozones which are subdivided into ecoprovinces, then ecoregions and then ecodistricts as the smallest unit of ecosystems.

The variables used in this study to investigate the geographical or ecological variability of decomposition are:

Ecozone: The biogeographic region based on the distribution of ecology and terrestrial organisms. There are 15 terrestrial ecozones in Canada as well as 5 marine ecozones.

Ecodistrict: The smaller subdivision of an ecozone based on ecology, biology, and geography. There are 1021 ecodistricts in Canada.

The distribution of cases was plotted by their assigned RLDV value on a Canadian map with an overlay of ecozones in an attempt to identify regional or ecological patterns; however no geospatial analysis was conducted using ArcGIS 9.3. There were only two ecozones with sufficient sample sizes to facilitate any type of comparisons: the Pacific Maritime (Lower Mainland area of, British Columbia) and the MixedWoods Plains (Toronto/Ottawa area, Ontario). Comparisons of the mean RLDV for all ecozones were conducted as well as a comparison of the mean ADD scores and PMI in days for each stage of decomposition for both ecozones.

3.8.2. *Part III, Q2: Is it Possible to Associate Certain Types of Alternate States of Decomposition to Specific Geographical or Ecological Regions of Canada?*

Global Information System (GIS) software was used to examine the distribution of alternate states of decomposition in Canada. The distribution of cases with alternate states of decomposition was plotted on a Canadian map with an overlay of ecozones in an attempt to identify regional or ecological patterns. The frequency and distribution of alternate states of decomposition such as mummification and moulding were evaluated to determine whether they could be associated to a specific region or ecozone.

The geographical distribution of baseline and alternate decomposition using GIS

A series of spatial analysis were conducted for cases in this study to determine whether the distribution of faster or slower baseline decomposition (RLDV) or alternate state of decomposition had a geospatial pattern. The same methods used to geocode and map cases in Section 3.7.2.5. for the independent variables, were used in this section to examine regional and ecological variability.

The distribution of cases by ecozone (Figure 4.111), and the distribution of cases by their RLDV were mapped within Canada (Figures 4.113). The Distribution and frequency of cases of alternate states of decomposition such as moulding (Figure 4.118) and mummification (Figure 4.120) were produced to examine whether any alternate state could be associated to a geographical region. The methodology used to calculate the RLDV for each case has been described in Section 3.7.2.1. The geographical location for each case was taken from the police files.

Table 3.4. List of maps examining the geographical variability of baseline and alternate decomposition within Canada

Map Figure	Variables examined	Data source for each variable
Figure 4.111	Distribution of **cases by ecozone**	Information taken from case records
Figure 4.113	Distribution of **RLDV** across Canada Above & below 1 standard deviation	Information taken from case records
Figure 4.118	Distribution of **Moulding** within BC In winter & summer	Information taken from crime scene & autopsy photographs and case records
Figure 4.120	Distribution of **Mummification** across Canada Indoors & Outdoors	Information taken from crime scene & autopsy photographs and case records

3.9. Part IV: Determine the Reliability of PMI Estimations Methods Based on Human Decomposition in Canada

The aim of the last section of the study was to evaluate the reliability and practicality of any PMI estimation method based on the visible level of decomposition of found human remains in Canada. The first aim is to test an existing ‘universal’ method proposed by Vass (2011), and the second to examine the variability in decomposition within the Canadian dataset to determine whether any PMI estimation method would be practical or advisable for use in the medico-legal arena.

The two specific aims or this part of the study are:

1. Can the “Universal Formula” (Vass 2011) be used to reliably predict the PMI for cases in Canada?
2. Based the biological, regional and site specific variability in decomposition; what is the potential to produce useful and reliable PMI estimations based on the visible state of decomposition for cases in Canada?

3.9.1. *Part IV, Q1: Can the "Universal Formula" (Vass 2011) be used to Reliably Predict the PMI for Cases in Canada?*

Vass (2011) has proposed two 'Universal' formulas to calculate the PMI for bodies above and under the ground. As implied by the title, this study proposed that these formulas can be used to produce an accurate PMI estimation for a body in any context and all geographical locations. These formulas are based on several *constants*, or universal laws of decomposition based on observations made of human decomposition at ARF in Knoxville, Tennessee over a time span of multiple years (Vass 2011). The validity of these *constants* has been tested using cases from this dataset. The accuracy of formulas I to accurately predict the PMI for bodies decomposing on the surface has been tested using a group of ten cases from this study.

One of the proposed universal laws is that soft tissue decomposition concludes at an accumulated temperature of 1285 ± 110 ADD score. To test the validity of this premise, the average ADD scores were calculated for stage 8 decomposition to determine whether or not it exceeded this maximum of 1285 ADD. Another proposed universal law was that the contribution of moisture to decomposition could be calculated at a constant factor of 0.0103. The validity of this premise was tested by using the formula with this factor to calculate the PMI for ten surface decomposition cases. The calculated PMI was compared to the known PMI for these 10 cases to determine whether the moisture factor for Knoxville Tennessee could reasonably be applied to cases in Canada.

The minimal qualifications for surface cases to be used with Formula I are that they must have more than 1 day PMI, without scavenging, not exposed to freezing temperatures and no adipocere formation (Vass 2011:35). From the total 104 cases in the outdoor surface dataset in this study, less than half (50 cases) met those standards. A group of 10 cases were randomly selected from the qualifying cases to represent a range of PMIs. This group of 10 cases was used to assess the overall accuracy of Formula 1 to calculate relatively accurate PMI estimates for Canadian cases. Instead of a classification system using numerical stages, the Universal formula utilized a percentage to estimate the progression of decomposition. To correct for the differences in the decomposition scales, each of the stages of decomposition from this study ranging from 1 to 8 (the cases with a zero score were not included) were multiplied by a factor of 12.5 to convert the stages to a percentage scale of 12.5 to 100%. The mean humidity and temperature values (degree Celsius) were calculated for these cases using the *Canadian Climate Data and Information Archive*. The environmental data was taken from the closest weather station, for the day that the body was discovered (according the Universal Formula methodology). The PMIs calculated using Formula 1 were compared to the actual known PMI. The error rate between the calculated and known PMIs was provided in actual PMI days as well as the ratio of error for each case.

Formula II was designed to estimate the PMI for buried bodies (Vass 2011). To utilize this formula, the quantified amount of soil moisture and soil temperatures were necessary. This information was not available for the retrospective cases in this study from online databases, police case files or ViCLAS data. However, this formula also utilized universal laws established through experiments and observations by Vass at ARF (Vass 2011). However, the fundamental premise of formula II involves a proposed ratio of 4.6 for the deceleration of time it takes a body to decompose under the surface compared to on the surface. This 4.6 ratio for buried bodies was tested using the buried cases within this dataset. This calculation was based previously performed experiments involving the decomposition of three buried bodies at ARF (Rodriguez and Bass 1985), in addition to observations made by Vass (2011) throughout his tenure at the facility. A comparison was made between the 4.6 ratio, and the ratios calculated using the 22 buried and 96 surface cases in the Canadian dataset. Vass did not specify whether the 4.6 rate applied to the ADD score or PMI days. Both PMI and ADD score ratios were provided for each of the stages of decomposition for comparative purposes.

3.9.2. ***Part IV, Q2: Based the Biological, Regional and Site Specific Variability in Decomposition; What is the Potential to Produce Useful and Reliable PMI Estimations based on the Visible State of Decomposition for Cases in Canada?***

The intent of this section was to determine, based on the results of this study, whether or not it would be possible to produce reliable and useful PMI estimations based on the visible variability of decomposition in Canada. Any PMI estimation would necessarily require a small enough error rate to make it useful for death investigators in a forensic context. The results of the first three parts of this study were reviewed, and new analysis conducted, to address the question of the estimation of reliable PMI for cases in Canada.

The inherent variability within the process of decomposition was examined to determine which process (autolysis or putrefaction) or specific stage of decomposition occurred with reasonable predictability (part I). To assess the predictability of the escalating error rates for the progression of decomposition, trend analysis was conducted using the confidence intervals which had been calculated for each stage of decomposition (associated to mean ADD in days). Trend analysis was conducted for the larger indoor and outdoor datasets and used the exponential growth as opposed to the linear model for the analysis. This analysis was conducted to assess the predictive ability of the data in relation to the confidence intervals with the increasing progression of decomposition.

An assessment was conducted of the variables identified during this study as contributing in some manner to the progression of decomposition (part II). The results from the multivariate regression analysis were used to determine which variables or complex of variable contribute to the progression of decomposition in outdoor, indoor, water and burial type scenes. Based on these variables, an assessment of the identified predictive and contributing variables was made to determine whether it would be possible to create a predictive model for decomposition in a specific scene type in Canada.

To examine the geographical variability in decomposition (part III), simple regression analysis was conducted to correlate the mean ADD scores and PMI days to the stages of decomposition for ecozones 8 and 13. Due to sample sizes only stages 0, 1, 2 and 5 were used for the comparison. Based on the summary or re-analysis of data from parts I, II and III, a determination was made regarding the feasibility of a national or regional methodology to estimate the PMI. A determination was also been made regarding the practicability of PMI estimations for specific stages of decomposition in specific scene types considering the associated error rates.

4. Results

The results of this study have been presented in this chapter. The discussion of the results will follow in Section 5. The results have been presented in four main parts as reflected in the methods chapter:

1. The baseline progression of decomposition in the four scene types in Canada. The presence and extent of the alternate states of decomposition in these four scene types.
2. The identification of variables which impact the progression of decomposition in the four scene types.
3. The geographical variability of decomposition and alternate states of decomposition in Canada.
4. An evaluation of the 'Universal formulas' (Vass 2011) to estimate PMIs and the potential for PMI estimation within the Canadian dataset.

4.1. Part 1: Define and Describe Decomposition in Canada

The progression of decomposition has been provided in the successive stages of decomposition and associated to the accumulation of time (PMI in days) and temperature (ADD score). The quantitative progression of decomposition is represented by the mean PMI in days and ADD scores calculated with an associated confidence interval for each stage of decomposition. The qualitative progression of decomposition is represented by the description of the visible changes occurring to the body throughout the progression of decomposition. The quantitative and qualitative progression of decomposition has been provided for decomposition outdoors, outdoors in burials, indoors and in water. The prevalence and frequency of each of the alternate states of decomposition such as mummification, adipocere formation or moulding has been presented as it relates to each scene type.

4.1.1. *The Normal Progression of Human Decomposition: Outside in Canada*

The surface environment includes all bodies at scenes which are not within a closed structure, in water or buried under the ground. The cases outside which involve burial or water will be discussed separately. Bodies decomposing on the surface are subject to a complex of variables. They are not protected by a structure from the extremes of heat, cold, precipitation or sunlight. There is a complex of variables in the immediate environment of the body which may impact decomposition. These variables may include temperature extremes, precipitation, sun exposure or impacts by insects and scavengers. The evaluation of which variables affect decomposition outdoors will be presented in a subsequent section.

The purpose of this section is to determine what the normal progression of decomposition is for bodies outside in Canada. The progression of decomposition has been presented according to the stages defined by the classification system and quantified by both the ADD score and the PMI in days. Photographs and descriptions have been provided to describe the range of common visible changes occurring to the body during the progression of decomposition outside on the surface.

A limitation for this type of retrospective study is that the progression of a body cannot be evaluated over time, only the level of decomposition at the time of discovery. The timing of the change between the stages or the time within each of the stages of decomposition is unknown. The assessment of the level of decomposition is considered to be a minimal value as the body could have been in that stage of an unknown period of time. The majority of the cases in this study were discovered during the earlier stages of decomposition compared to a lower frequency in the later stages (Figure 4.1). The discovery rates are due to social factors for the victim and population density for that geographical region. For most areas in Canada, the longer the post mortem interval for a body; the higher the chance of discovery.

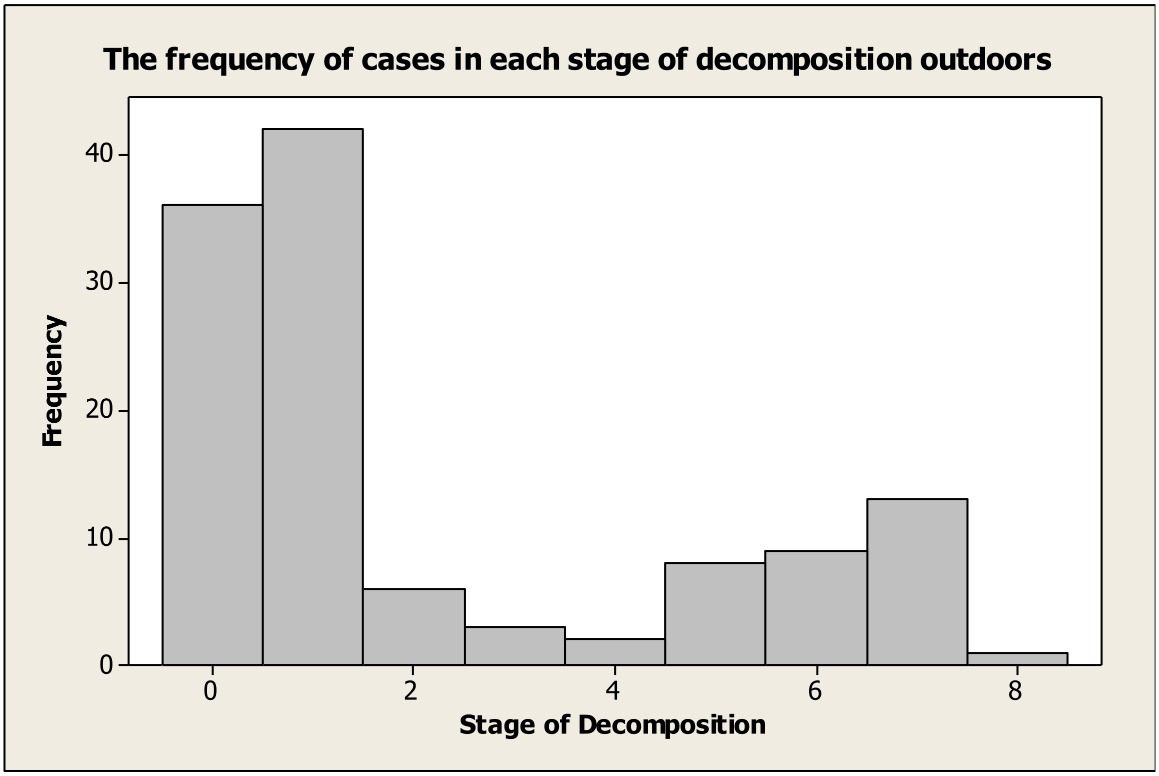


Figure 4.1. ***The frequency of cases in the outdoor scene type discovered at each stage of decomposition. There are more cases in stage 0 (fresh) and 1 compared to all the other stages of decomposition. Most bodies are discovered in the early stages of decomposition unless the body has been purposefully hidden.***

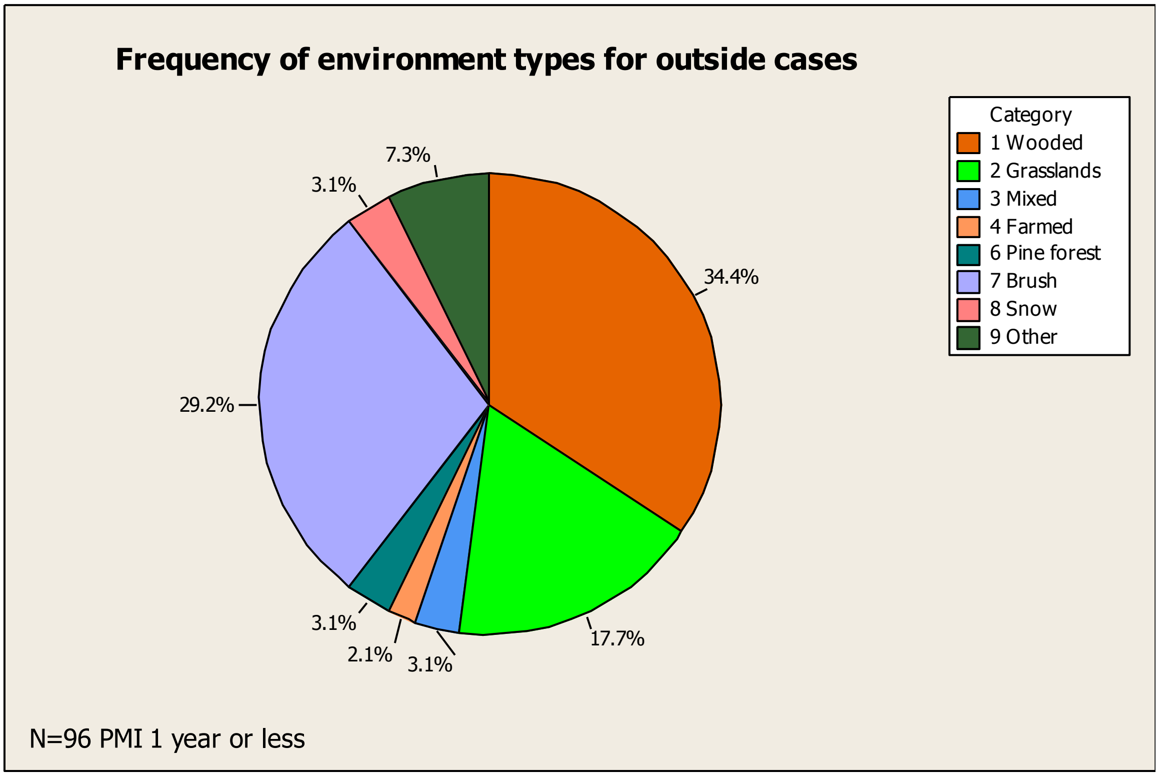


Figure 4.2. ***Bodies located outside on the surface were discovered in nine main types of environments. The most common environment is the wooded scene type. The least common type of environment was the cultivated field. The majority of the cases in this study are homicides. Environments which provide cover and protection from discovery are more common.***

The bodies in the outdoor surface group were located on a variety of surfaces and environments. The majority of bodies were found outside in wooded or brush environments (Figure 4.2). This would be expected given the general need for the suspect(s) to conceal a body and delay discovery for as long as possible. Very few of the cases found outside were exposed. Of the exposed cases, many had been dumped in gravel pits or along the side of the road. The impact of shade on the decomposition in wooded and sheltered areas will be examined in Section 4.3.3.3.

Quantitative Variability in Baseline Decomposition Outdoors

There are 96 cases within the study which were found outside on the surface with one year PMI or less. The mean ADD and PMI with associated confidence intervals (95%) were calculated for each stage of decomposition from stage 0 to 7 in the outdoor environment (Figures 4.11 and 4.12). There were no cases with one year PMI or less that were classified at stage 8 decomposition.

The interval plots show the error rate (95%) for the mean ADD score or PMI calculations for each stage of decomposition. The larger the error rate, the more variability in the data and the less reliable the mean calculations. The error rates appear to increase with the progression of decomposition.

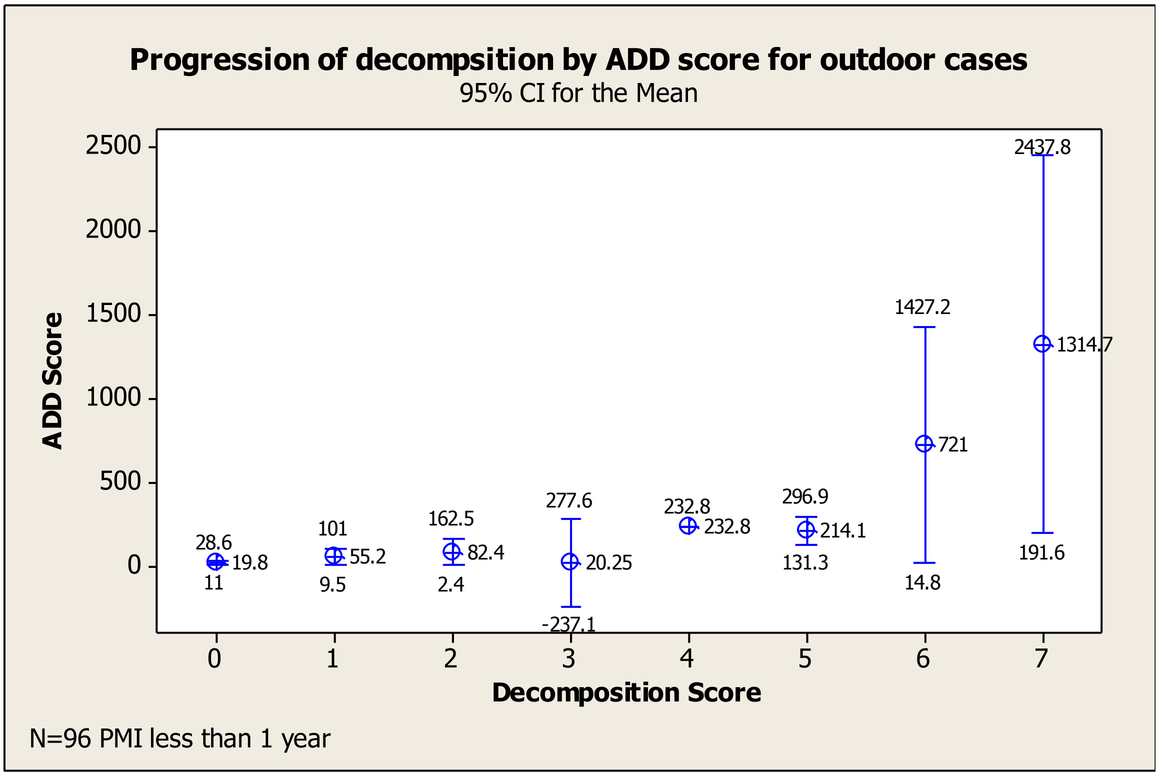


Figure 4.3. ***The mean ADD score is provided for each stage of decomposition with an associated Confidence Interval of 95%. The interval plots show an increased variability in the mean ADD score for stage 3, 6 and 7. Stage 3 represents the onset of putrefaction and stage 6 and 7 the onset of liquefaction and skeletonization. The accumulated temperature onset (ADD score) of putrefaction and liquefaction show higher levels of variability outside.***

The mean ADD scores and associated confidence intervals have been provided for each stage of decomposition outdoor scenes (Figure 4.3). There are no cases with stage 8 (fully skeletonized) with a PMI of less than one year in the study. This Interval plot shows a relatively small error rate for stages 0, 1, 2 and 5 compared to stages 3, 6 and 7. Figure 4.4 shows the same level of variability for those stages with PMI for the outdoor cases.

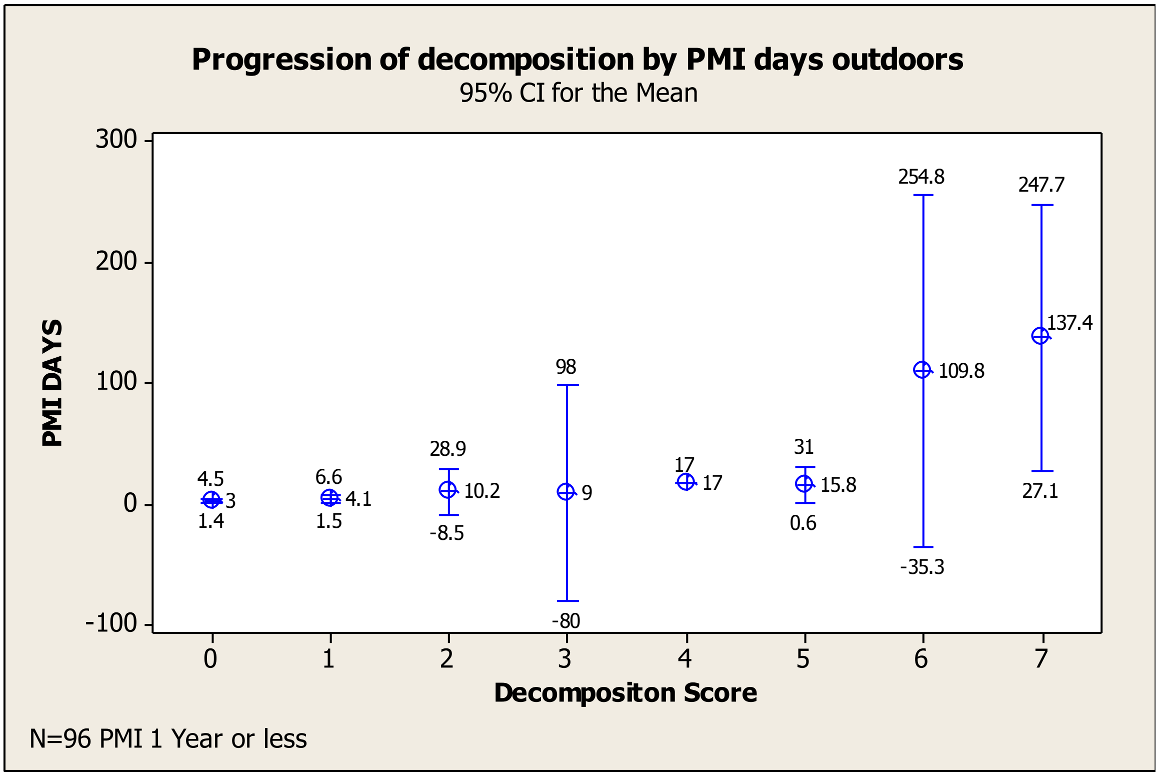


Figure 4.4. ***The mean PMI Days is provided for each stage of decomposition for outdoor cases with an associated Confidence Interval of 95%. Stages 3, 6 and 7 show the largest error rates and the highest amount of variability. Stage 3 is the onset of putrefaction and stages 6 the onset of liquefaction and skeletonization. The data suggests that there is considerable variability in the time a body may take to progress into putrefaction or begin to skeletonise outdoors.***

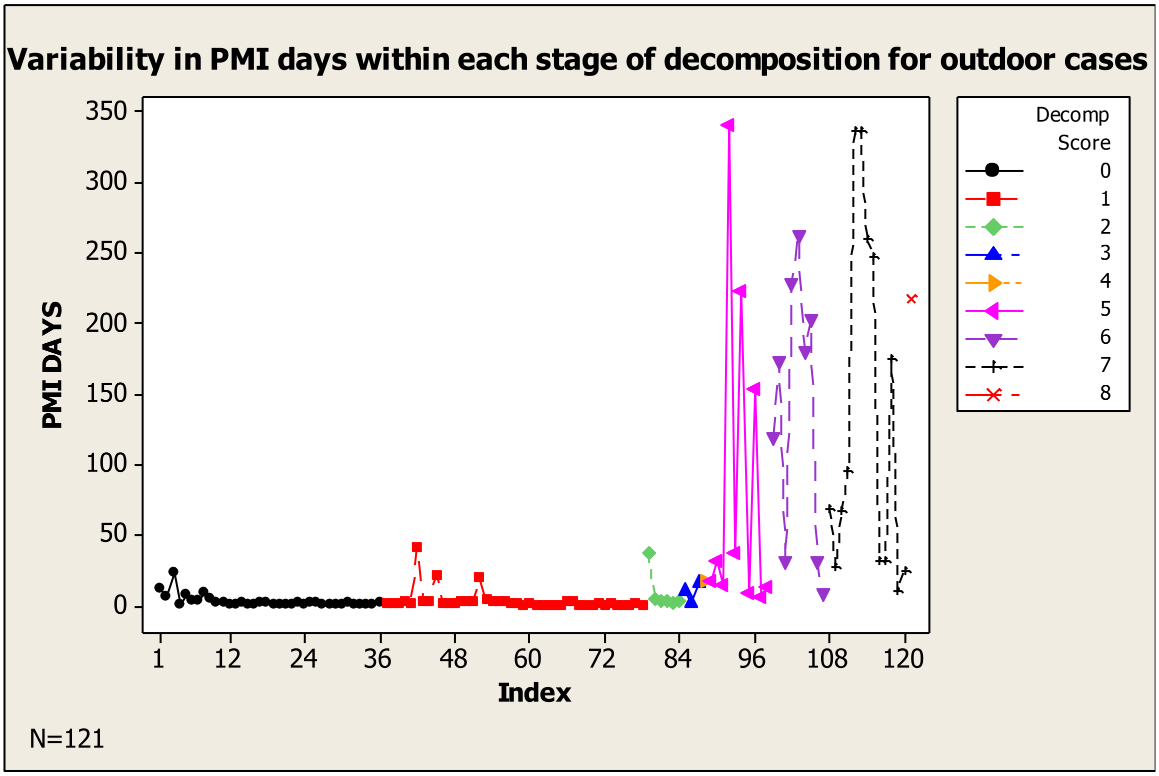


Figure 4.5. ***The range of PMI days for each stage of decomposition. There is a limited range in days for stages 0 to 3, however stages 5 to 7 shows a much larger degree of variability in PMI days. This variability suggests that from stage 5 onwards, a body may linger that stage of decomposition outdoors for a period of time before progressing to the next.***

There is a limited range of PMI days for stages 0 to 3 compared to an increasing range for stages 5 to 7 for decomposition outdoors (Figure 4.5). Stage 5 is the end stage of putrefaction which is characterized by black blood and a brown or black appearance to the tissue associated with the release of any gasses. The time ranges for Stage 5 to stage 7 demonstrate considerable variability whereas stage 0 to stage 4 has relatively limited temporal variability. This variability in the later stages of decomposition is seen with all scene types and is likely due to the natural processes of decomposition as opposed to the variability caused by the scene types.

The quantitative and qualitative progression of decomposition outdoors

The mean PMI in days and ADD scores have been calculated for each stage of decomposition outdoors. A description has been provided on the common visible traits recorded for bodies decomposing outdoors on the surface. The common visible traits have been provided with the assumption that there will be exceptions due to the specific conditions or context of each case.

Stage 0

Stage 0 represents those individuals who have no visible signs of decomposition. There is no visible discolouration (including lividity) or tissue change.

Based on a range of environmental conditions, the body may stay in this fresh state for a period of time. There are 33 cases at stage 0 on the surface within the Canadian data set These bodies can be in an exposed environment on the surface for an average score of 19.8 ADD (ADD will always represent a result in degrees Celsius) with a 95% confidence interval of 28.6 at a maximum, and 11 at a minimum. In relation to time a body can stay in the fresh state on average, for 3 days. The maximum is 4.5 days and the minimum 1.4 days outside on the surface in Canada.

Stage 1

Stage 1 is defined as visible onset of decomposition. This first sign of decompositional change is generally characterized by the onset of lividity with a red discolouration to the tissue caused by the settling of blood cells in the dependant portions of the body. Lividity can be useful to death investigators as it "fixes" after a period of time and establishes the position of the body in contact with any surfaces. Anomalous lividity can indicate that a body has been moved after the lividity has fixed. Lividity can also reflect the presence of tight fitting clothing, and in some instances, the pattern and texture of that clothing or covering.

There are 38 cases with stage 1 decomposition found on the surface outside. For the first visible stage of decomposition, the average ADD temperature to reach this level is 55.2 with a maximum of 101 and a minimum of 9.5 degrees Celsius within the 95% confidence interval. In relation to time, it takes an average of just over 4 days (4.1) to reach this stage with a maximum of 6.6 and minimum of 1.5 days in the 95% confidence interval.

Stage 2

Stage 2 is defined at the first onset of tissue change in the body. This change can include skin slippage, bullae formation, hair and nail loss as well as the onset of the decomposition of blood in the veins which is called ‘marbling’ (Figure 4.6).

Figure 4.6. Decomposition of the blood and the increased pallor of the tissue increase the visibility of the veins and arteries. This is called “marbling” and is seen in the upper chest area of this individual.

There are five cases in the outdoor surface dataset with stage 2 decomposition. The average ADD score for stage 2 is 82.4. The 95% confidence interval is from 162.5 to 2.4. The average PMI in days for stage 2 is 10.2 days. The 95% confidence interval is to a maximum of 28.9 days.

Stage 3

Stage 3 is the onset of putrefaction which is generally characterized by a greenish discolouration to the blood and a greenish, blue or yellow discolouration to the tissue associated with the onset of swelling.

There are only 3 cases in this group which may contribute to the large error rate. The average ADD for stage 3 is 20.25. The 95% confidence interval goes to a maximum of 277.6. The average PMI for stage 3 is 9 days. The 95% confidence interval goes to a maximum of 98 days.

Figure 4.7. A green discolouration is seen to the tissue and visible blood in the area of the head.

This individual shown in Figure 4.7 has a greenish discolouration to both tissue and blood seen in his face. The onset of swelling can be seen in the area of the eyes. Putrefaction originates in the abdominal area. The aerobic bacteria propagate throughout the body by way of the circulatory and lymphatic systems.

Stage 4

Stage 4 is characterized by the full discolouration and bloat of putrefaction. The visible sign of this stage is characterized by a purple discolouration of the blood and a red colour of the tissue associated with full distension and purge fluids. There is only one case in the outdoor surface group with this stage of decomposition. The ADD for this individual was 232.8 and the PMI 17 days.

Stage 5

Stage 5 decomposition is characterized by the final stage of putrefaction which consists of a loss of bloat and a black appearance to the blood with a black or brown discolouration to the tissue.

Figure 4.8. ***Black and brown tissue discolouration is visible on the torso and head of this individual. Tissue can discolour as the result of desiccation.***

The individual shown in Figure 4.8 has a brown discolouration to the tissue which is particularly visible in the abdominal and upper leg region. There are signs of blacked blood and tissue in the area of the face. The discolouration of this individual is also affected by a certain amount of desiccation of the abdominal and genital areas.

There are five cases in with stage 5 decomposition on the surface outside. The average ADD for stage five is 214.1. The 95% confidence interval goes to a maximum of 296.9 and a minimum of 131.4. The average PMI for stage 5 is 15.8 days. The 95% confidence interval is from 31 days at a maximum to 0.6 days at a minimum.

Stages 6 & 7

Stages 6 is the onset of skeletonization with less than half the bone exposed. Stage 7 represents a body where more than half the bone exposed. There are only four cases in the outdoor surface group at stage 6. The average ADD is 721. The 95% confidence interval goes from 1427.2 at the maximum to a minimum of 14.8. The average PMI for stage 6 is 109.8 days. The 95% confidence interval goes from 254.8 to a minimum of zero. There are a total of 8 cases at stage 7 outside on the surface. The average ADD for this group is 1314.7. The 95% confidence interval is from 2437.8 at a maximum to 191.6 at a minimum.

Figure 4.9. Skeletonization has started under the clothing with the exposure of the fibula.

For the individual in Figure 4.9, the stage of the tissue is in a post putrefaction state with the majority remnant tissue in a black or brown in colour. The soft tissue is in a state of liquefaction which is not easily seen from the photographs. The removal of the tissue for this individual has been assisted by maggot activity.

There are no cases at stage 8 on the surface outside with no remnant tissue.

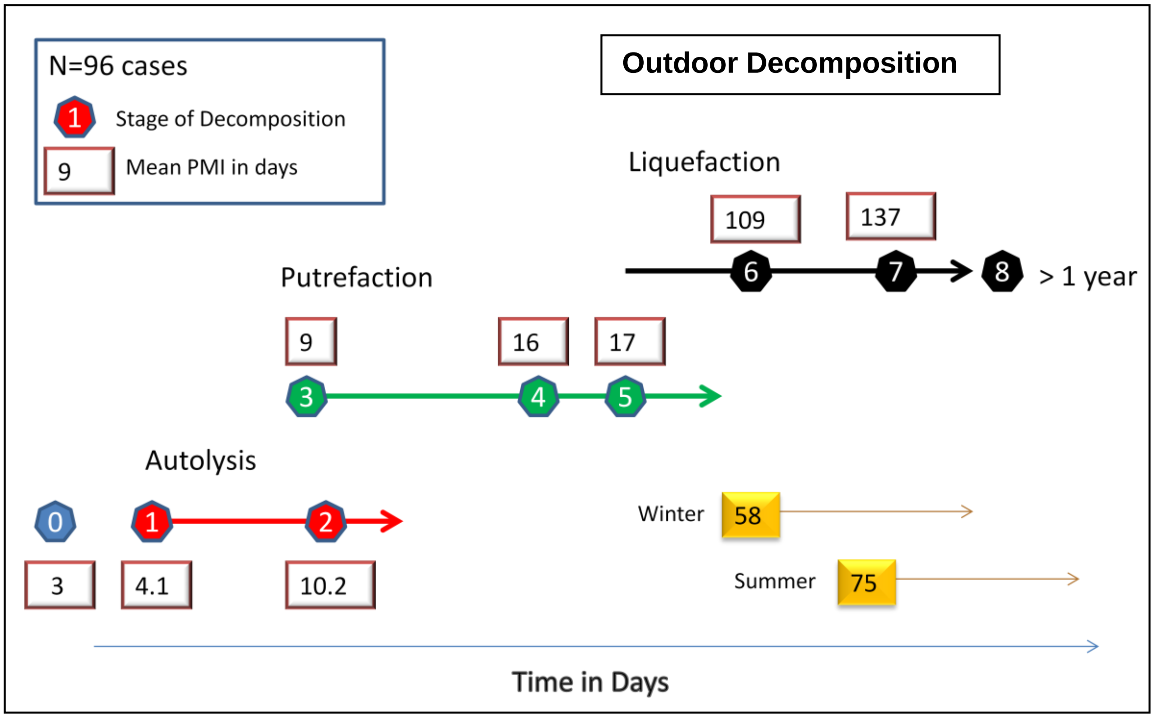


Figure 4.10. The summary of mean PMI days for each stage of decomposition for the outdoor dataset. The numbers in the coloured octagons represent the stage of decomposition. The red arrow represents autolysis, green putrefaction and black liquefaction and skeletonization. The number in the square boxes under the octagons is the mean PMI in days for that stage of decomposition. The numbers in the yellow squares represent the mean PMI days for the onset of mummification in winter compared to summer. N=96

For comparative purposes, the mean PMI days has been provided for each stage of decomposition outdoors (Figure 4.10). The three main processes of decomposition: autolysis, putrefaction and colliquation (skeletonization) are provided as coloured arrows with associated octagons representing the numbered stage of decomposition. There is an overlap in the time it takes to start and end each of these main processes of decomposition. The mean onset of mummification is provided in PMI days (in squares) by season for the outdoor group. It takes less time for the onset of mummification in winter compared to summer outdoors, which would suggest that the development of mummification relates more to lower humidity levels than higher temperatures.

Alternate States of Decomposition Outdoors: Mummification

Mummification is the process by which moisture is lost from the tissue due to evaporation. With the loss of moisture, the tissue will become dry and relatively hard. In some instances, the desiccation of the tissues of appendages or organs (eyes or tongue) will result in a black discolouration. Taphonomy researchers such as Galloway et al. (1989) and Bass (1997) include mummification as an expected state during the continuum of normal decomposition in their geographical location. The state of mummification was included by Megyesi et al. (2005) as an integral part of their total body score classification system. For the head and neck and limbs it appears during early decomposition as a discolouration and or browning at edges, drying of nose, ears and lips for the head, neck and limbs. Megyesi (2005) identifies mummification as a natural state of decomposition through all three of stages of early and advanced decomposition and skeletonization.

Only 11% of the outdoor cases demonstrated any visible development of mummification. Of the fourteen outdoor cases with mummification, only four occurred during the winter months (October to April). One involved very low temperatures in an arid environment (Saskatoon), however the other three cases were found in the relatively mild and moist lower mainland area of British Columbia. For these cases the mummification was anatomically limited to the fingertips and in one case, fingertips and face. The average ADD score for these three BC cases was 121 with an average PMI of 20 days. A comparison of these cases has been provided in Table 4.2. The results suggest that it takes more time for the onset of mummification during the summer months compared to the winter. The level of precipitation for both groups is similar and does not seem to be a factor in the onset of mummification. Temperature does not appear to be the mitigating factor for mummification as the average ADD score for the cases in the winter is higher on average compared to the summer (Table 4.1).

Table 4.1. Comparison of the average ADD score, PMI days and accumulated precipitation for outdoor cases with mummification by season

Season	ADD - Temperature	PMI - Days	Precipitation - mm
Summer (10 cases) (May to Sept)	62	75	75
Winter (5 cases) (October to April)	142	58	72

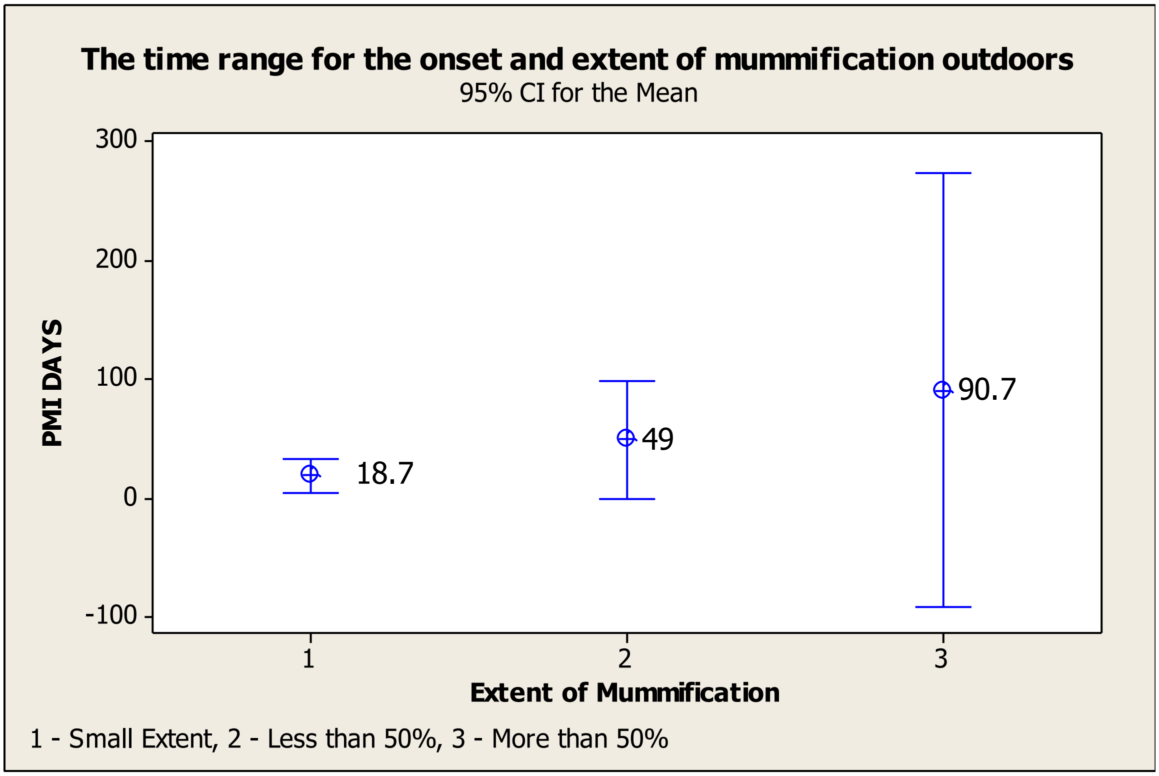


Figure 4.11. The mean PMI in days for presence of mummification outdoors. N=96. The average onset for the first visible signs of mummification outdoors is approximately 19 days. For a moderate amount of mummification it is 49 days and for more than 50% of the tissue to be mummified outside it takes on average 91 days.

There is an increasing time range for the presence and extent of mummification for cases outdoors (Figure 4.11). It takes on average approximately 19 days for the appearance of mummification on a limited amount of tissue. As the extent of mummification increases, so too does the variability in time. Mummification in the outdoor scenes would be associated with late stage putrefaction. The presence of mummification during the earlier stages of decomposition might suggest that the individual has spent a period of time indoors prior to being moved.

A review of mummification in outdoor cases during the summer months show the majority of the cases (80%) mummification of remnant tissues after a relatively long PMI. The average PMI for these cases is 62 days. In many of these cases the majority of the tissue has already been removed by either maggots or scavengers. The tissue is blackened in all cases and the differences are due to the location and extent of mummification. In the winter months, mummification is localized to finger-tips and faces during the early stages of decomposition. During the summer, mummification of the tissue is only seen during the very latest stages of decomposition after purification and the onset of skeletonization.

Figure 4.12. Mummification of the remnant tissue during late stage decomposition outdoors in the summer. This case has a PMI of 32 days, ADD of 485 degrees and precipitation of 75mm in Ecozone 10.

It can be concluded therefore that mummification in Canada is not as common as is found in arid environments such as the southern United States and appears to occur after a long post mortem interval. Mummification of the tissues is generally associated with remnant tissues during advanced decomposition and skeletonization (Figure 4.12). There is a difference in the normal appearance of mummified tissues during these stages of decomposition in Canada compared to the cases from other geographic locations.

4.1.2. *The Normal Progression of Human Decomposition: in Burials in Canada*

A burial occurs when a body had been covered partially or entirely by soil. The suspect will excavate a hole in the ground, place the body in it, and then cover it up with soil or debris. There are 22 cases in the outdoor group with less than 1 year PMI, where the body was partially or fully buried. There are 17 cases where the burial was considered to be shallow and 5 cases with a relatively deeper burial. A shallow burial is when at least some portion of the body is still visible.

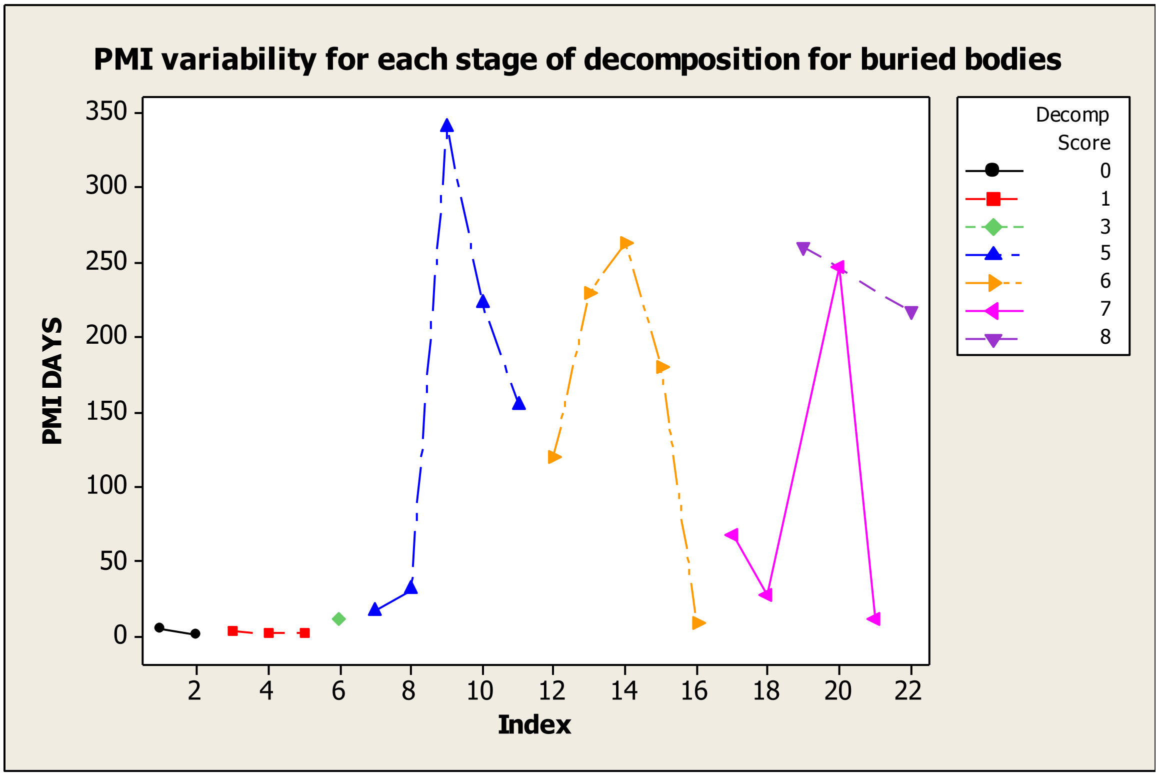


Figure 4.13. ***The variability in PMI days for each stage of decomposition for the burial scene type. There is an increase in variability with stage 5 decomposition (late stage of putrefaction). These results suggest that buried bodies in the later stage of decomposition may linger in that stage and subsequent stages for a variable period of time. N=22***

The time plot for decomposition in burials demonstrates the same pattern of increased variability in the later stages of decomposition compared to the outdoor scene type (Figure 4.5). Stages 0 – 3 do have a limited range of variability, compared to stage 5, 6 and 7.The is an overlap in the time ranges between stages 7 and 8 (Figure 4.13).

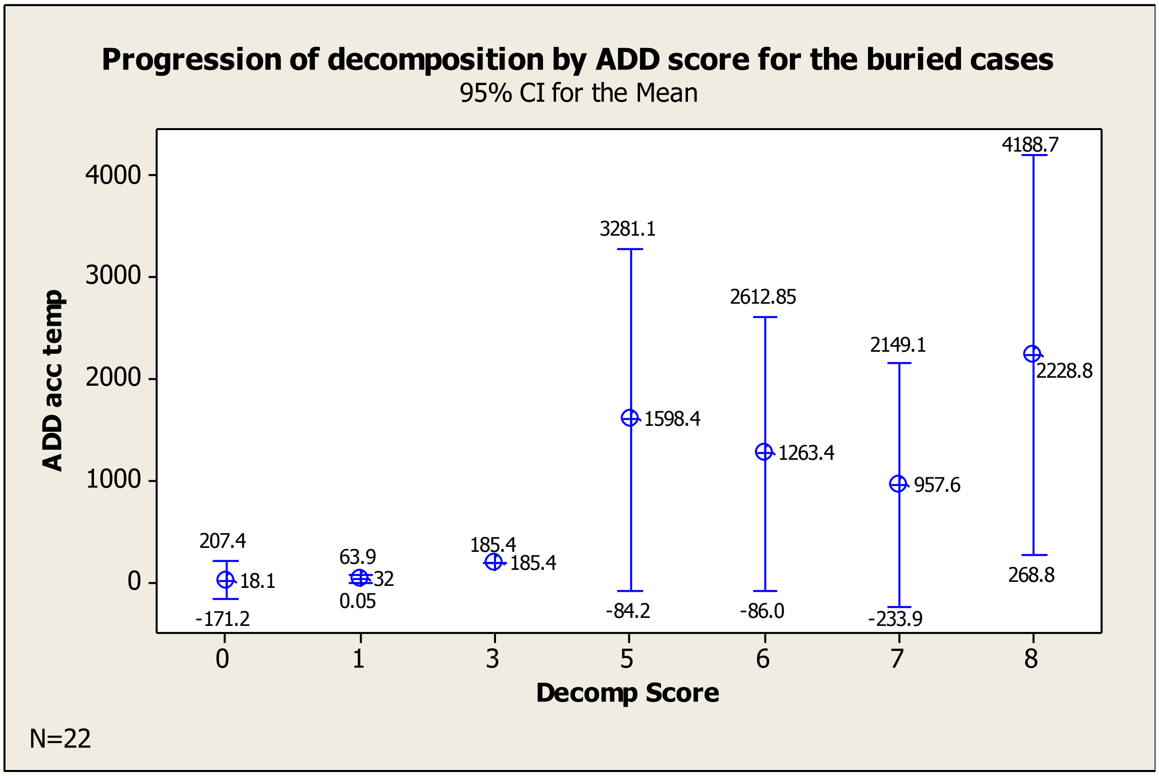


Figure 4.14. ***The mean ADD scores for each stage of decomposition for the buried cases. Stages 5 onward show the largest variability. Stage 4 is not represented by this data set. N= 22***

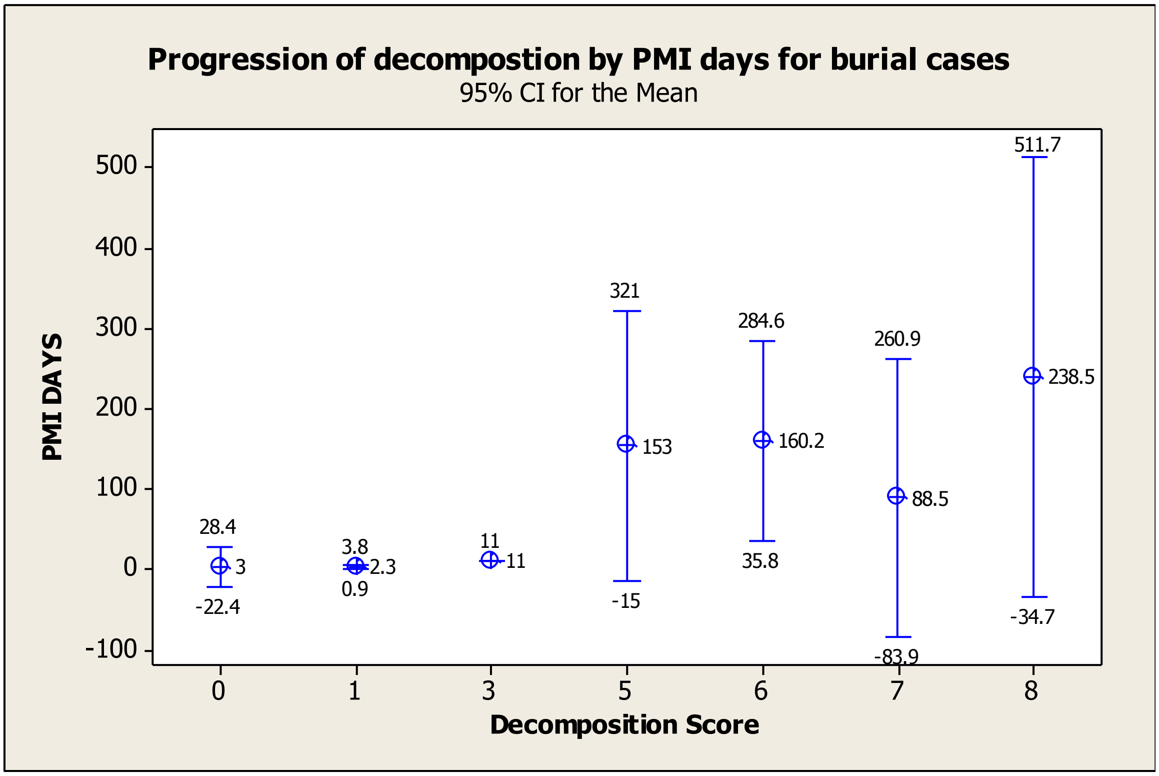


Figure 4.15. ***The mean PMI days for each stage of decomposition for the buried cases. Stage 5 onward has the most variability. These stages are associated late stage putrefaction and onset skeletonization. There is more predictability in the time it takes to reach the earlier stages of decomposition as opposed to the later ones. Stage 4 is not represented. N=22***

Figure 4.14 & 15 provide the mean ADD scores and PMI days with associated confidence intervals for each stage of decomposition for the buried cases. As with the outdoor dataset, there is less variability in the earlier stages of decomposition compared to the later stages. There are only 22 cases in this group, and as such the results should be treated with caution give the small sample size.

The normal progression of decomposition in burials

There are 22 burial cases in this dataset. This section describes the baseline progression of decomposition for the cases in this dataset.

Stage 0

Stage 0 is the first stage after death where there is no visible sign of decomposition. There are two cases in the buried group. The average ADD for a buried individual is 18.1.The 95% confidence interval for ADD is to a maximum of 207.4. The average PMI is 3 days for the buried group. The 95% confidence interval is to a maximum of 28.4 days.

Stage 1

Stage 1 represents the first signs of visible change to the body, which is generally caused by the onset of lividity. There are three cases in this group with level 1 decomposition. The average ADD for a buried individual in stage 1 is 32. The 95% confidence interval for ADD is 63.9 to a minimum of 0.1. The average PMI is 2.3 days for stage one. The 95% confidence interval is from 3.8 days to 0.9 days. Stage 1 for buried cases look very much the same as in the outdoor surface group.

There are no stage 2 decomposition cases in the buried group.

Stage 3

Stage 3 is characterized with the onset of putrefaction. The blood has a green discolouration; the tissue is greenish, blue or yellow with the onset of swelling. There is only one case with stage 3 decomposition in the buried group. The ADD for this case is 185.4 and the ADD is 11 days.

Figure 4.16. Green, yellow and red discolouration is visible on all parts of the body

There is a predominately green as to opposed to brown discolouration of the tissue in association with red discolouration (Figure 4.16). Swelling can be seen in the face area by the marks in the midsection caused by the strain of tissue on the existing clothing.

There are no cases in the buried group with stage 4 decomposition.

Stage 5

There are five cases in the buried group that represent stage 5 decomposition. This stage is characterized by black blood and brown to black tissue.This is the post bloat stage of decomposition.

Figure 4.17. The tissue has a distinct brown colour with a visible loss of cohesion for the subcutaneous tissue.

There is a brown discolouration of the tissue and as well as a loss of tissue cohesion and onset of liquefaction. Some the tissue of the lower right leg of this individual has been exposed by colliquation (Figure 4.17).

The average ADD for stage 5 in the burial environment is 1598.4. The 95% confidence interval is to a maximum of 3281.1. The average PMI for stage 5 is 153 days. The 95% confidence interval goes to a maximum of 321 days.

Stage 6

There are 6 cases with stage 6 decomposition. This is the first stage of skeletonization with brown to black tissue and less than ½ of the bone exposed.

Figure 4.18. The tissue has a light brown colour with blackening in the upper shoulder and head areas. Adipocere is visible in the upper thigh area.

The individual shown in Figure 4.18 demonstrates the black tissue discolouration in the shoulder and face area. Some of the tissue of this individual had begun the process of saponification. The average ADD for stage 6 decomposition in the buried group is 1263.4. The 95% confidence interval is to a maximum of 2212.9. The average PMI for stage 6 is 160 days. The 95% confidence interval is between 284.6 to 35.8 days.

Stage 7 & 8

There are five cases with stage 7 decomposition and two at stage 8. Stages 7 and 8 represent various stages of skeletonization. With the brown coloured tissue in progress of liquifaction, stage 7 is scored when more than half the bone is exposed. Stage 8 represents total skeletonization with only a small amount of renmant soft tissue.

The average ADD for stage 7 decomposition in a buried environment is 957.6. The 95% confidence interval is to a maximum of 2149. The average PMI for stage 7 is 88.5 days. The 95% confidence interval is 260.9 at a maximum and 83.9 at a minimum. The average ADD for stage 8 decomposition in a buried environment is 2228.8. The 95% confidence interval is from a maximum of 4188.7 to a minimum of 268.8. The average PMI for stage 8 decomposition is 238.5 days. The 95% confidence interval is to a maximum of 511.7 days.

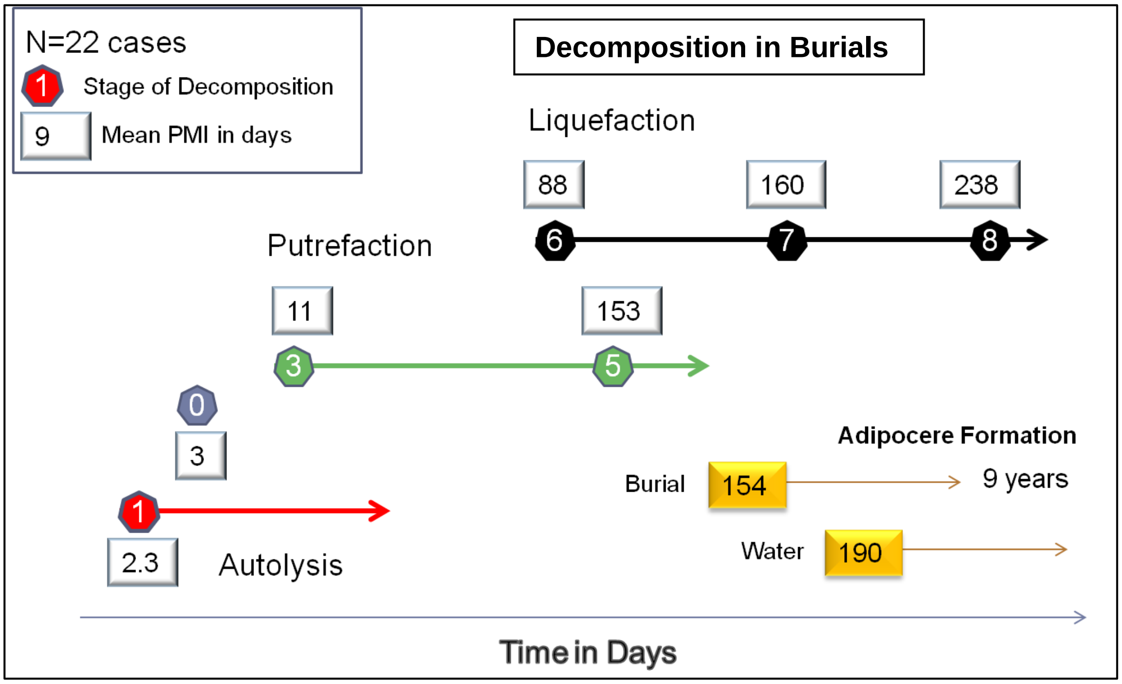


Figure 4.19. The mean PMI days for each stage of decomposition in a burial. The numbers in the coloured octagons represent the stage of decomposition. The red arrow represents autolysis, green putrefaction and black liquefaction and skeletonization. The number in the square boxes next to the octagons is the mean PMI days for that stage of decomposition. The numbers in the yellow square boxes represent the mean PMI days for the presence of adipocere formation in the burial versus the water environment. N=22

The progression of decomposition by PMI in days has been provided for decomposition in a burial scene type (Figure 4.19). The mean PMI in days is shown for the presence of adipocere in the buried and water scene types. The mean PMI days are provided in the octagons along the arrow of the specific decomposition process. The mean PMI in days is provided in the yellow rectangles for the presence of adipocere.

The Comparison of Late Stage Decomposition Outdoors vs. Burials

There are fifteen cases in the database in the last stages of decomposition (stages 6, 7 & 8). The last stage, stage 8, involves total removal of all tissue for full skeletonization. There are 5 of these cases. The other ten cases involve bodies which have decomposed outside and have onset skeletonization; either less than or more than half of the bone is exposed. This last stage of decomposition before full skeletonization is characterized by a liquefaction of the tissue. The colour of the tissue is brown in colour with a wet appearance. A total of eight out of ten cases are burials where the body has been partially or totally buried (Table 4.2).

Table 4.2. Comparison of Average ADD, PMI and Precipitation of Outdoor Cases in the Last stages of Decomposition (6 to 8) without Mummification

Environment	Average ADD Temperature	Average PMI days	Average Precipitation mm
Buried (8 cases)	1137	152	384
Surface (2 cases)	455	103	127

The ADD score for the buried and partially buried cases was calculated based on surface temperatures. Both cases on the surface did demonstrate brown tissue liquefaction; however that was associated to large maggot masses. The impact of insect involvement and the soil moisture has more influence than levels of precipitation.

Figure 4.20. An example of brown/black liquefaction in advanced decomposition for a buried body. This case as an ADD score of 2627 and a PMI of 339 days with a total precipitation of 613 mm in ecozone 14.

Based on the cases in the results for bodies in the advanced stages of decomposition outdoors, there are two different trajectories of tissue decomposition. For bodies that decompose on the surface, the tissue will take on a black, hardened and mummified appearance with bone exposure. They may also take on a brown wet appearance if there is extensive presence of maggots and insects. For bodies that decompose partially or totally under the ground, a brown wet appearance can be expected (Fig. 4.20).

Alternate States of Decomposition in Burials: Adipocere Formation

There are only 4 (18%) cases out of the possible 22 which demonstrate adipocere formation in a burial context. Of the four buried bodies with adipocere formation, there is only one which has full body adipocere development. The PMI for this individual is nine years (Figure 4.21).

Figure 4.21. Full body adipocere development after 9 years in a deep grave

This individual was exhumed from a relatively deep clandestine grave in the lower mainland area of British Columbia, wearing multiple layers of synthetic clothing. The other three cases have minimal adipocere development on limbs in association brown liquefaction.

The ratio of time it takes to decompose in a burial vs. the surface

Rodriguez (1997) stated that the rate of decomposition for a buried body is eight times slower than a body decomposing on the surface (1997:459). This ratio relates to the amount of time a body takes to reach each relative stage of decomposition. This ratio appears to be based on qualitative observations of decomposition at the "Body Farm" facility in Knoxville Tennessee. When the mean ADD scores and PMI days are compared for the buried versus the surface rate of decomposition, this 8 to 1 ratio is not validated in the Canadian dataset (Table 4.3).

Table 4.3. PMI and ADD comparisons for surface and buried cases

Outdoors	**Stage 0**		**Stage 1**		**Stage 3**	
Average	PMI	ADD	PMI	ADD	PMI	ADD
Surface *(98 cases)*	3	20	4	55	9	20
Buried *(24 cases)*	1	3	3	28	11	185
Ratio Difference	***x 3**	***x 6.7**	***x 1.3**	***x 2**	x 0.8	x 9.25
	Stage 5		**Stage 6**		**Stage 7**	
	PMI	ADD	PMI	ADD	PMI	ADD
Surface	16	18	10	38	227	1893
Buried	153	1598	642	6226	122	1242
Ratio Difference	x 9.6	x 89	x 6.4	x163	* **x 1.9**	* **x1.5**

Note: Four cases which involved hanging/suspended bodies were removed from the outdoor dataset * = Burial cases faster than surface cases. Stages 2, 4 and 8 are missing from the buried dataset

The ratio of time or temperature it takes a body to decompose in either the buried or surface environments differs during the process of decomposition. For stage 1 of decomposition, with the first visible onset of decomposition, the rate of decomposition for both time and temperature appears to be faster in a buried environment. Within the Canadian database it takes less time and temperature under the surface to achieve stage 7 (more than half skeletonization) as opposed to the surface. There are no stages where an 8 to 1 ratio for time is seen for the buried cases versus the surface. Therefore, the assumption of an 8 to 1 ratio for the time it takes to decompose under versus on top of the surface cannot be validated based on this dataset.

The impact of depth of burial on decomposition

Rodriguez and Bass (1985) attribute the depth of the burial as one of the most important variables in the rate of decomposition for buried bodies. Due to the small sample sizes for the burial dataset, it was only possible to compare stage 6 decomposition for shallow versus deeply buried cases (Table 4.4).

Table 4.4. The comparison of the mean PMI and ADD scores to achieve stage 6 decomposition for shallow versus deeply buried bodies.

Stage 6 Decomposition	Mean PMI in days	Mean ADD Score
Shallow Burial	203	1139
Deep Burial	191	2193

A comparison of the average time and accumulated temperature appear to be relatively similar. The deeply buried cases took less time to reach stage 6 than the bodies at a more shallow level (Table 4.4). Half of the cases in the shallow graves were fully clothed, the other half naked while the group of bodies in the deep burials were fully clothed. A *t*-test was conducted to examine the results for each stage of decomposition in the outdoor set and in the buried set for ADD and PMI to determine whether or not there was a significant difference (Tables 4.5 & 4.6).

Table 4.5. Comparison of ADD scores for surface vs. burial

Paired T for ADD –Surface & ADD- Burial				
	N	Mean	StDev	SE Mean
ADD -Surface	6	391	526	215
ADD- Burial	6	676	688	281
Difference	6	-285	613	250
95% CI for mean difference: (-928, 358)				
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.14 P-Value = 0.306				

Note: The paired T-Test was conducted on stages 0, 1, 3, 5, 6 and 7 only.

The results of the paired *t*-test shown in the above tables (Tables 4.5 & 6) demonstrate that there is no significant difference between the average PMI and ADD scores for each of the relevant stages of decomposition for bodies in the outdoor surface and buried groups.

Table 4.6. Comparison of PMI in days for surface burial

Paired T for PMI - Surface & PMI - Burial				
	N	Mean	StDev	SE Mean
PMI - Surface	6	46.5	60.5	24.7
PMI - Burial	6	69.7	74.7	30.5
Difference	6	-23.1	64.1	26.2
95% CI for mean difference: (-90.4, 44.1)				
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.88 P-Value = 0.417				

Note: The paired T-Test was conducted on stages 0, 1, 3, 5, 6 and 7 only.

4.1.3. *The normal Progression of Human Decomposition: Indoors in Canada*

The indoor dataset is the largest in the study with 193 cases. The indoor cases involve the decomposition of a body within a contained structure. The ADD scores for the indoor cases were calculated as an accumulation of a standard 20 degrees for each PMI day. The majority of indoor cases were discovered in the early stages of decomposition or within a few days after death (Figure 4.22). There was only one case at stage 6, and none at stage 7 and 8. Although the maximum PMI for an indoor case is 85 days, skeletonization did not occur indoors for the cases in this dataset. The majority of bodies found decomposing inside retain the soft tissue regardless of temperature, season or insect involvement.

The mean ADD scores and PMI in days for each stage of decomposition has been calculated for the indoor scene type.

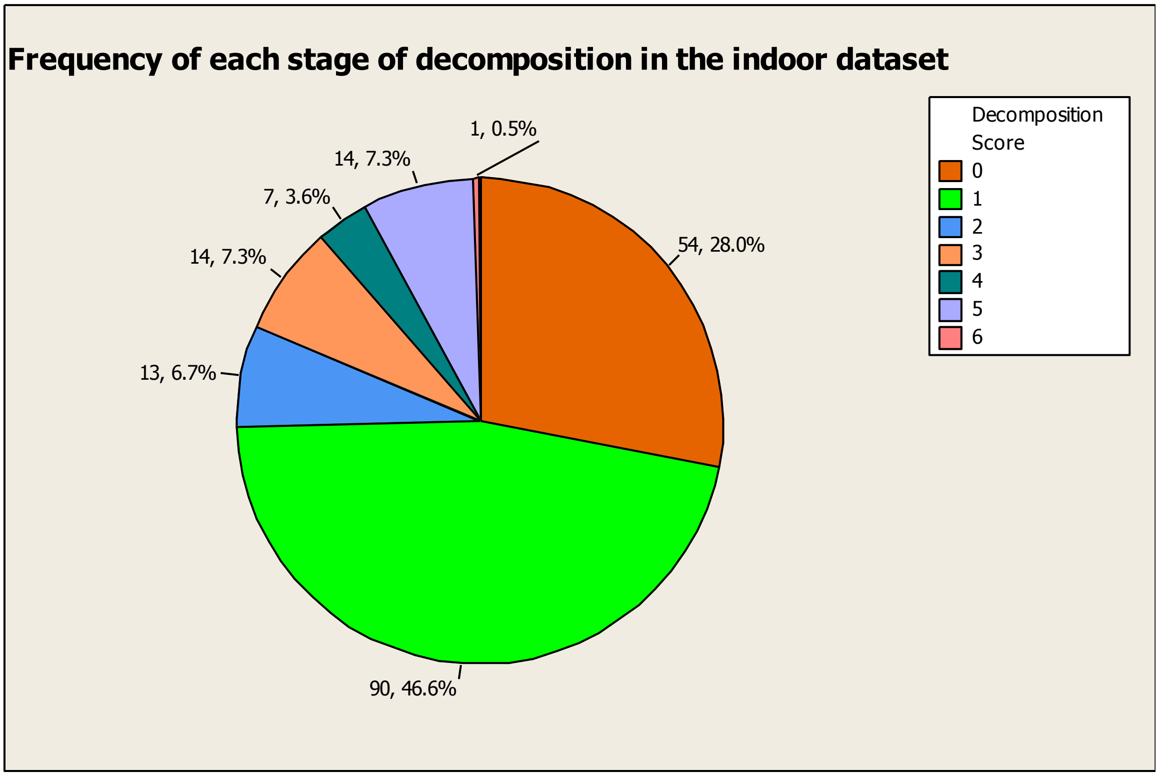


Figure 4.22. ***The pie chart shows the relative frequency of each stage of decomposition of the indoor dataset. The stage with the highest level of representation is stage 1, the onset of autolysis. There are less bodies in an advanced stage of decomposition due to the early discovery of most bodies. Stages 7 & 8 are not represented. N=193.***

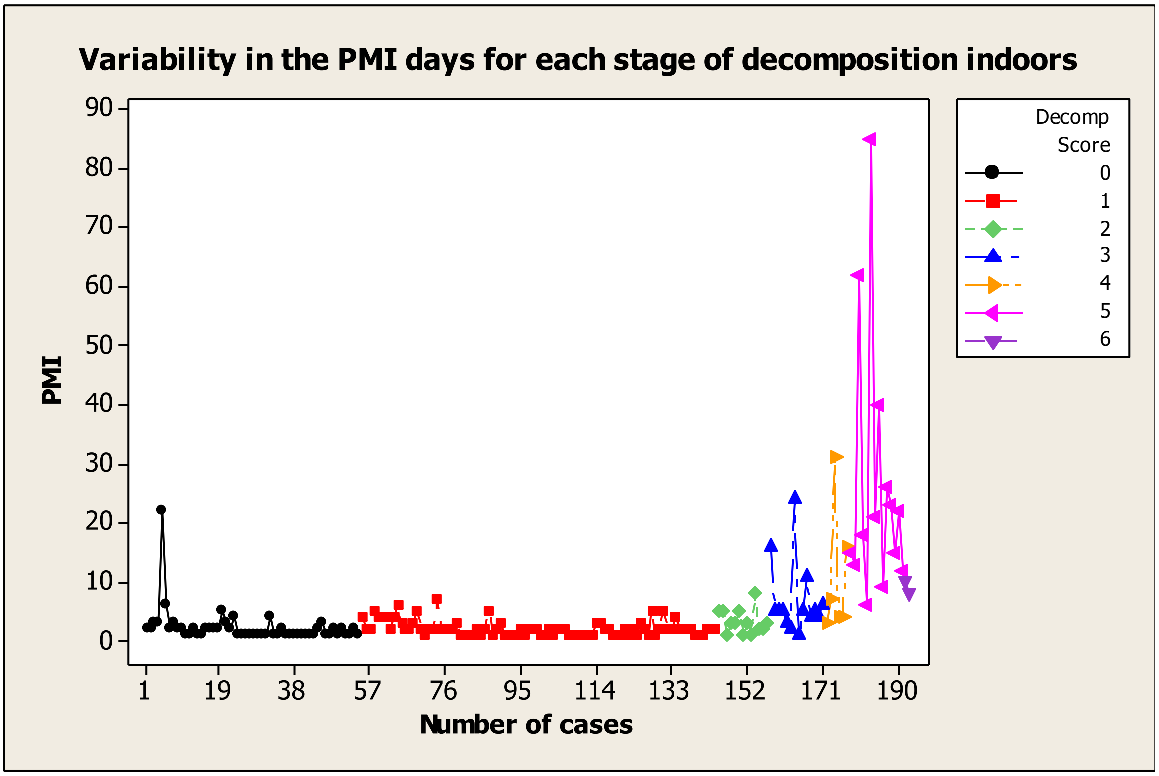


Figure 4.23. ***The variability in the PMI days for each case at each stage of decomposition. The time ranges for stages 0 to 2 are relatively predictable (with one exception). The onset of putrefaction at stage 3 shows an increasing level of variability with the largest variability at stage 5. Stage 7 and 8 are not represented in the indoor dataset. N=193***

The indoor cases show a steady progression in the variability of PMI days with subsequent stages of decomposition (Figure 4.23). Stages 5 to 8 have a smaller range of variability in the indoor dataset compared to the outdoor dataset. The later stages of decomposition have the largest time range variability indoors, which is similar to the results for all other scene types. In the indoor group, stage 3 to 5 decomposition which encompasses the onset of putrefaction and skeletonization shows the greatest temporal variability.

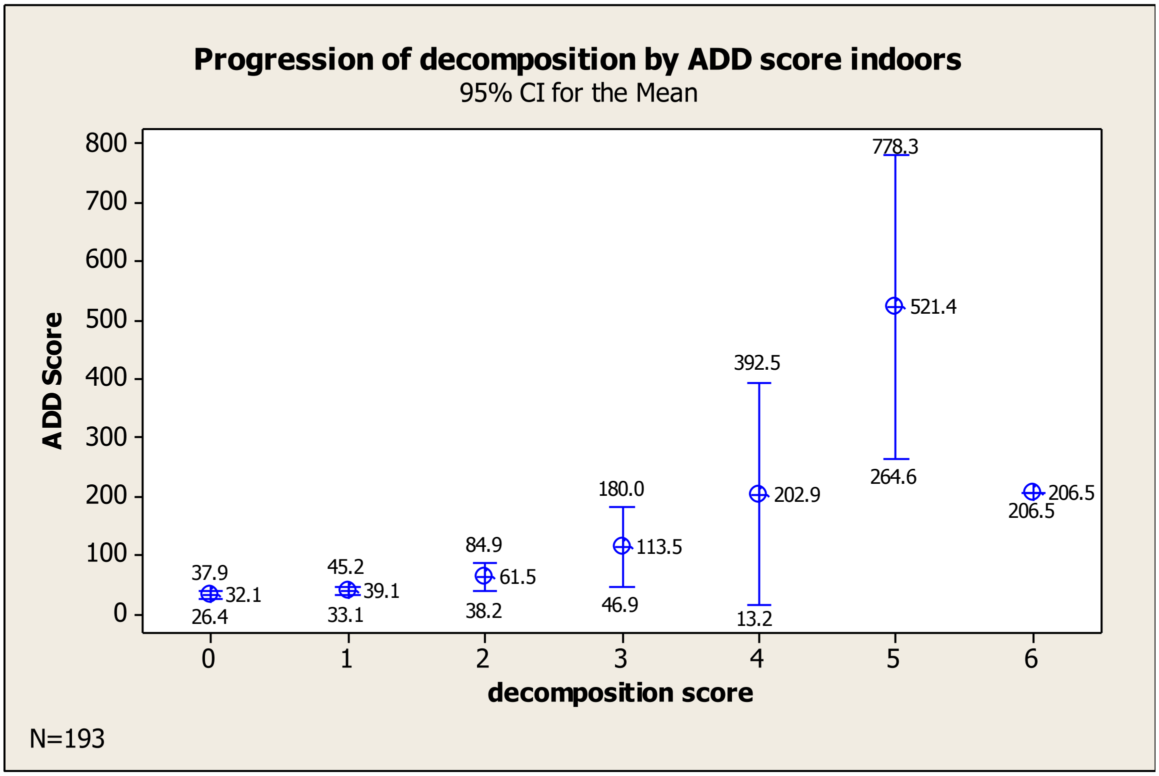


Figure 4.24. ***The mean ADD score for each stage of decomposition for the indoor dataset. There is a progression in variability of the ADD score with the progression of decomposition. The stages of putrefaction have the largest range of ADD scores. There is only one case relatively anomalous case at stage 6 indoors. The data shows that bodies indoor may linger at stage 5 without progressing to skeletonization of a period of time.***

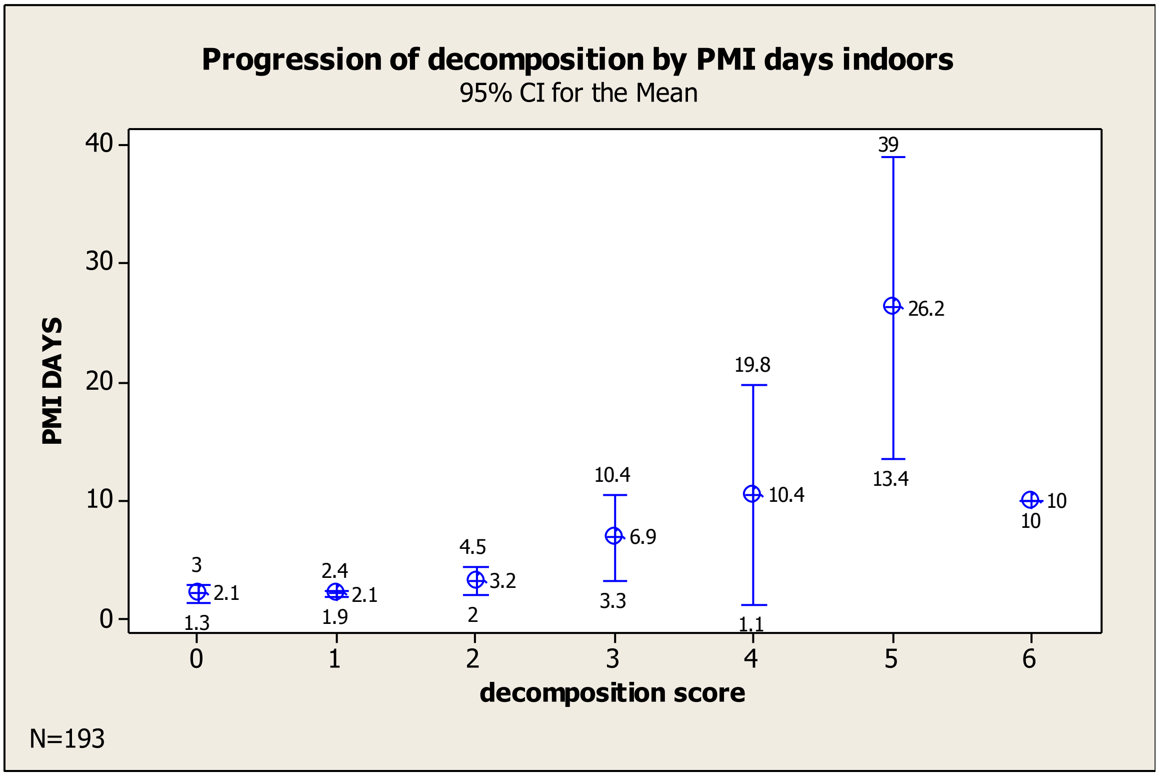


Figure 4.25. The mean PMI days is provided for each stage of decomposition with an associated 95% confidence interval for the indoor dataset. The error rate increases with the progression of decomposition. There is only one relatively anomalous case at stage 6 decomposition. The data suggests that bodies indoors may linger in stage 5 and 6 for a period of time and not progress into skeletonization for a period of time.

The mean ADD score and PMI in days for each stage of decomposition have been provided with an associated 95% confidence interval for all indoor cases (Figure 4.24 and 4.25). As was seen with the burial and outdoor environment, the data demonstrates a greater variability at the onset of putrefaction with stage 3. The variability is less extreme however with decomposition in the indoor group compared to the outdoor and buried groups.

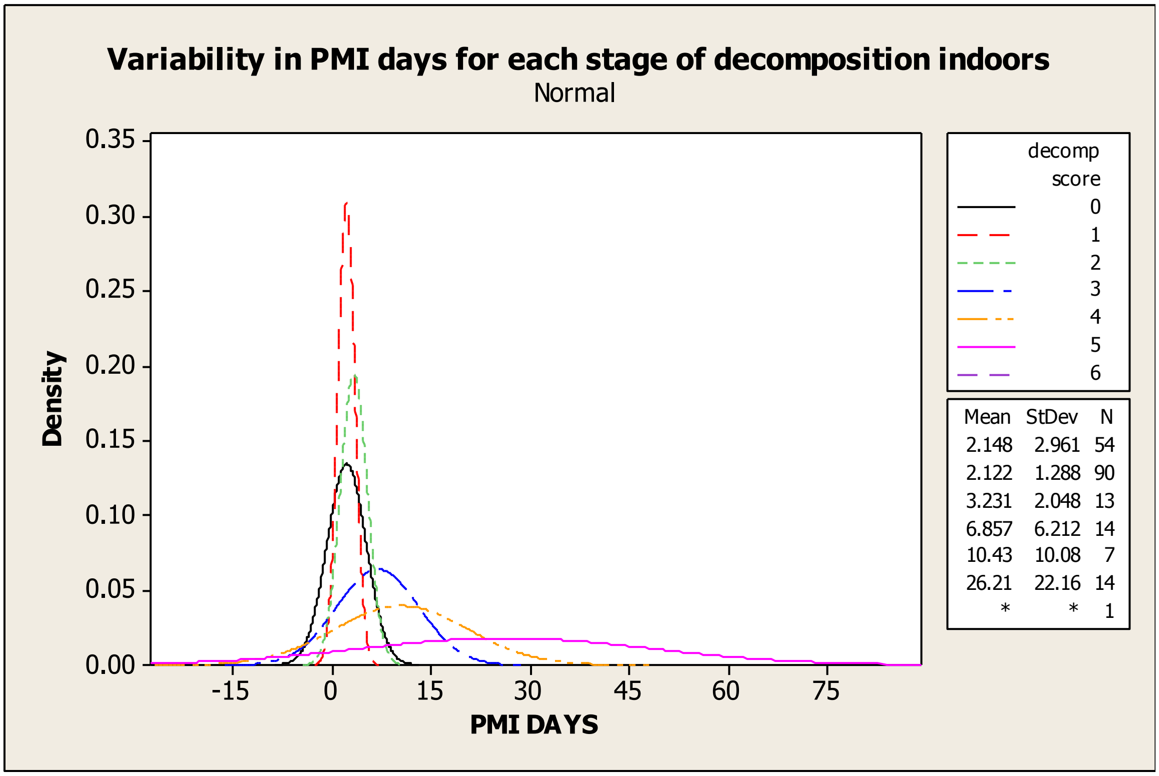


Figure 4.26. ***The distribution of mean PMI days for each stage of decomposition indoors. The stages with the largest standard deviations are stages 3, 4 and 5 during putrefaction. N=193***

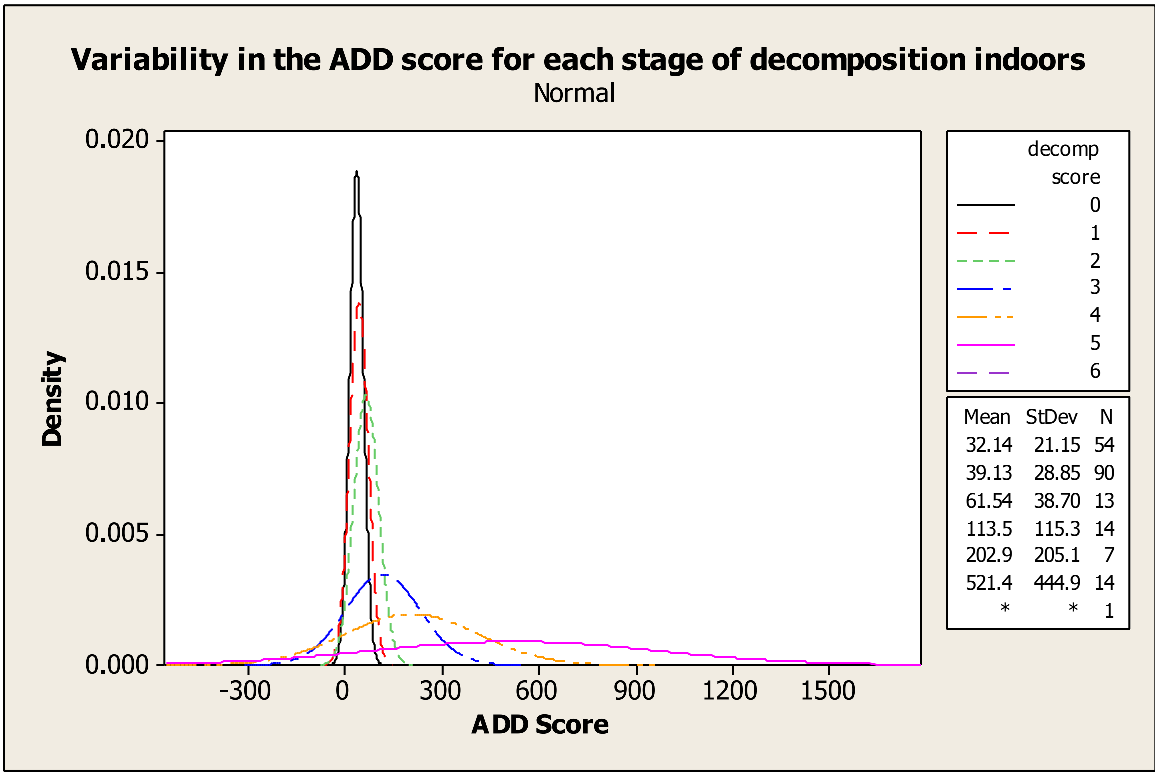


Figure 4.27. The distribution of the ADD score for each of the stages of decomposition indoors. Stages 3, 4 and 6 show the widest distribution and largest standard deviation. There is only one case with stage 6 decomposition. N=193.

The curves for the range in ADD scores and PMI days for each stage of decomposition indoors demonstrated a wider distribution of the later stages of decomposition (Figures 4.26 and 4.27). The earlier stages of decomposition had the smallest standard deviations compared to the later stages.

The Normal Progression of Decomposition Indoors

The progression of decomposition in the stages defined by the classification system using the ADD score and PMI in days.

Stage 0

Stage 0 decomposition is the phase after death and before the first visible signs of decomposition. Bodies can be in this fresh state for a period of time. There are 54 cases with stage 0 decomposition in the indoor dataset. The mean ADD score for stage 0 is 32.1. The 95% confidence interval is 37.9 at a maximum and 26.4 at a minimum.

The average PMI for stage 0 is 2.1 days. The 95% confidence interval is from 1.3 days at a minimum and 3 days at a maximum.

Stage 1

Stage 1 decomposition is the first stage of visible decomposition. The first visible sign of decomposition is generally lividity and consists of a reddish staining of the tissue due to the settling of blood cells in the dependant parts of the body after death.

There are 90 cases in the indoor dataset with stage 1 decomposition. The average ADD score for this group is 39.1. The 95% confidence interval for the ADD score is 45.2 at a maximum and 33.1 at a minimum. The mean PMI for stage one decomposition indoors is 2.1 days. The 95% confidence interval for PMI is from 2.4 days at a maximum and 1.9 days at a minimum.

Figure 4.28. Lividity is seen in the hand of a hanging suicide victim. The discolouration is gravity and position dependant

Lividity is visible on the hand of a hanging victim (Figure 4.28). Blood has settled by way of gravity in the hand.

Stage 2

Stage 2 decomposition represents late stage autolysis which is recognised by the first signs of tissue changes which would include; bullae formation, skin slippage, hair or nail loss. Decomposition of the blood is seen as a blue to purple coloured marbling pattern on the tissue. There are 13 cases classified as stage 2 decomposition in the indoor dataset. The average ADD score for stage two decomposition indoors is 61.5. The 95% confidence interval for the ADD score is 84.9 at a maximum and 38.2 at a minimum. The average PMI for stage 2 indoors is 3.2 days. The 95% confidence interval for PMI is 4.5 days at a maximum and 2 days at a minimum.

Stage 3

Stage 3 decomposition is characterized by the onset of putrefaction. The blood starts to take on a green discolouration and the tissue a green, to blue or yellow colour associated with tissue swelling.

There are 14 cases with stage 3 decomposition in the indoor dataset. The average ADD score is 113.5. The 95% confidence interval for the ADD score is 180 at a maximum and 46.9 at a minimum. The average PMI for stage 3 decomposition indoors is 6.9 days. The 95% confidence interval for the PMI is from 10.4 days at a maximum and 3.3 days at a minimum.

Stage 4

Stage 4 decomposition is characterized by the full discolouration and bloat of putrefaction. The visible sign of this stage is characterized by a purple discolouration of the blood and a red colour of the tissue associated with full distension and purge fluids.

There are 7 cases with stage 4 decomposition in the indoor dataset. The average ADD score is 202.9. The 95% confidence interval for the ADD score is 392.5 at a maximum and 13.2 at a minimum. The average PMI for stage 4 decomposition indoors is 10.4 days. The 95% confidence interval is from 19.8 days at a maximum and 1.1 days at a minimum.

Stage 5

There are 14 cases with stage 5 decomposition in the indoor dataset. The average ADD score for stage 5 indoors is 521.4. The 95% confidence interval for the ADD score is 778.3 at a maximum and 264.6 at a minimum. The average PMI for stage 5 indoors is 26.2 days. The 95% confidence interval for PMI is 39 days at a maximum and 13.4 days at a minimum.

Stage 6

Stage 6 decomposition is the onset of skeletonization with less than half bone exposure. There is only one individual in this group (Figure 4.29). He had an ADD of 206.5 and a PMI of 10 days. This individual was already extremely emaciated as the result of an illness (AIDS). This rapid rate of mummification could be considered anomalous due to the specific condition and context of the individual.

Figure 4.29. Bone was exposed in the temple area of the skull. This is an anomalous case as the individual was emaciated due to AIDs at the time of his death and died during a hot dry season.

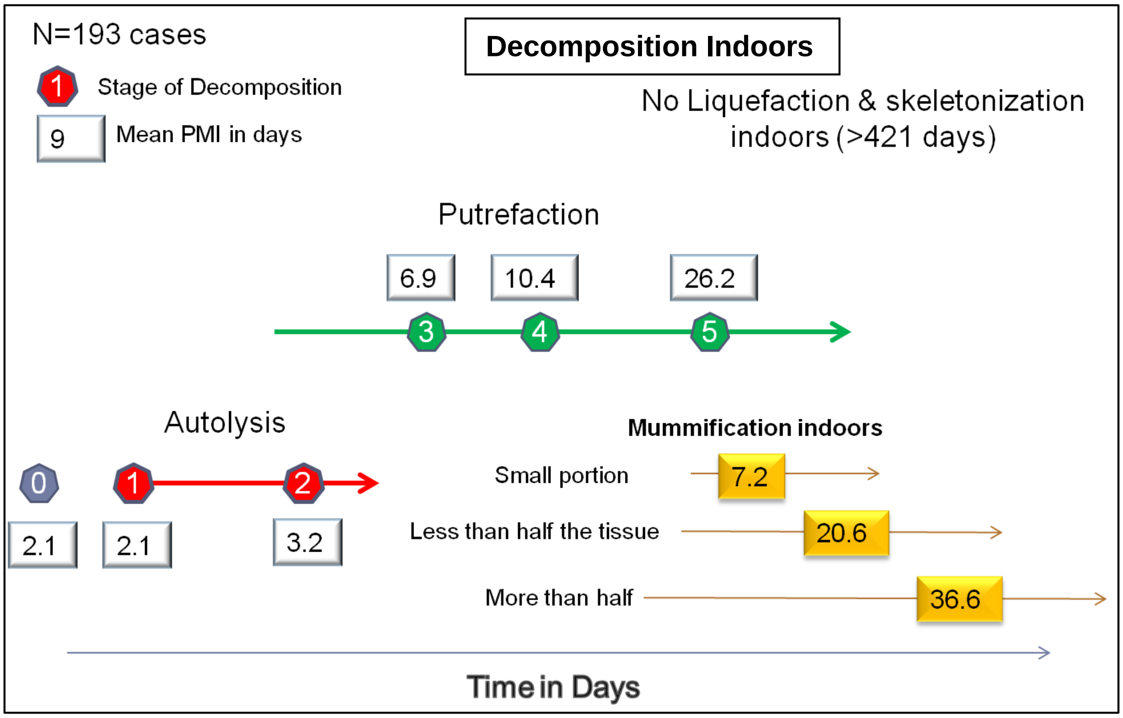


Figure 4.30. The progression of decomposition by mean PMI days for indoor cases. The numbers in the coloured octagons represent the stage of decomposition. The red arrow represents autolysis, green putrefaction and black liquefaction and skeletonization. The number in the square boxes next to the octagons is the mean PMI days for that stage of decomposition. The numbers in the yellow squares represent the mean PMI days for the presence and extent of mummification indoors. N=193

The progression of decomposition for the indoor cases is provided in mean PMI days (Figure 4.30). The process of autolysis and putrefaction are represented in the inside dataset without skeletonization. There is a small temporal overlap between autolysis and putrefaction. The yellow squares represent the mean PMI in days for the presence and extent of mummification.

Alternate States of Decomposition Indoors: Epidermal Bullae

There are 14 cases in the indoor dataset at stage 5 decomposition. Seven of these cases have epidermal bullae (Fig. 4.31). Epidermal bullae occur when there is a collection of fluid between the epidermis and dermis during autolysis or putrefaction. The fluid inside the epidermal bullae can be reduced leaving dry epidermal bullae in which the initial separation of the dermis and epidermis is still visible. The dried bullae take the appearance of 'onion skin' of the surface of on the tissue (Fig. 4.32).

Figure 4.31. ***Epidermal bullae (water collecting between the epidermis and dermis) is visible on the torso and legs of this individual decomposing indoors.***

Figure 4.32. ***'Onion skin', representing a dry epidermal bullae on the left hip***

Seven cases at stage 5 decomposition demonstrated mummification without the presence of epidermal bullae (Figure 4.32).

Table 4.7. The frequency of epidermal bullae at stage 5 decomposition indoors

Case #	PMI	ADD	Month	Drugs	Alcohol	COD	Cloths	Insect	LOC
52	15	280	4	0	1	1	2	2	ON
73	13	240	4	0	1	1	1	2	ON
194	6	120	11	1	0	2	2	2	ON
217	40	800	7	1	0	2	2	2	ON
220 *	9	180	3	1	0	2	2	0	ON
223	26	520	6	1	1	3	3	2	ON
335	12	240	4	0	0	2	2	2	ON
283	22	440	7	0	1	2	2	3	ON
Aver	**18**	**352**		**50%**	**50%**				

Note: The "COD" is Cause of death: 1 – homicide, 2-natural, 3- suicide. "Cloths": 3 fully clothed, 2 partial and 1 naked. 1 = yes, 0=no. "Loc" is location and ON represents Ontario. Case 220* located in front of open fridge (functioning).

The range of conditions for the presence of epidermal bullae has been provided in Table 4.7. Half of the cases have the involvement of alcohol or drugs. There was no commonality in season of death, cause of death, extent of clothes or insect involvement. Although all of the cases occurred in Ontario, there were a large number of cases in the indoor dataset from the Ottawa region.

Figure 4.33. Desiccation of the tissue without epidermal bullae in stage 5 decomposition indoors.

Table 4.8. The cases and variables of indoor cases without epidermal bullae at stage 5 decomposition indoors

Case #	PMI	ADD	Month	Drugs	Alcohol	COD	Clothes	Insect	LOC
34 *	421	8420	3	1	1	1	3	2	YK
190	62	1240	8	1	0	2	1	3	BC
192	18	360	7	0	1	4	3	3	BC
196	85	1700	12	0	0	2	2	0	ON
213	21	420	8	1	0	2	1	2	ON
238	23	460	6	1	0	2	2	0	ON
262	15	300	6	0	0	2	3	3	ON
283	22	440	7	0	1	2	2	3	ON
Aver	**35**	**703**		**57%**	**42%**				

Note: The "COD" is Cause of death: 1 – homicide, 2-natural, 4 is accidental. "Cloths": 3 fully clothed, 2 partial and 1 naked. 1 = yes, 0=no. "Loc" is location and ON = Ontario, BC is British Columbia and YK is the Yukon Territory. Case 34 excluded from averages as more than 1 year PMI.

A comparison of Tables 4.7 and 4.8 does suggest that the epidermal bullae are found in the earlier stages of stage 5 putrefaction. However there does not appear to be a reason why, in some cases, bullae do not form at all (Figure 4.33). These cases occur throughout the year, not just in the summer and seem to be associated to natural deaths.

Alternate States of Decomposition Indoors: Mummification

Mummification is present in 20 (10%) indoor cases. The more advanced the decomposition, the more prevalent the occurrence and extent of mummification (Table 4.9). Regardless of the post mortem interval (to a maximum of 421 PMI days), decomposition does not progress past the initial stages of skeletonization (stage 6). Many of the instances of mummification in the indoor context in Canada involve the mummification of the extremities, particularity the fingertips. The average PMI for mummification indoors is 7.2 days for a small portion of mummification (fingertips and faces), 20.6 days for less than half the tissue and 36.6 days for more than half the tissue (Figure 4.34). Total mummification was generally not found in the indoor scene in the Canadian dataset

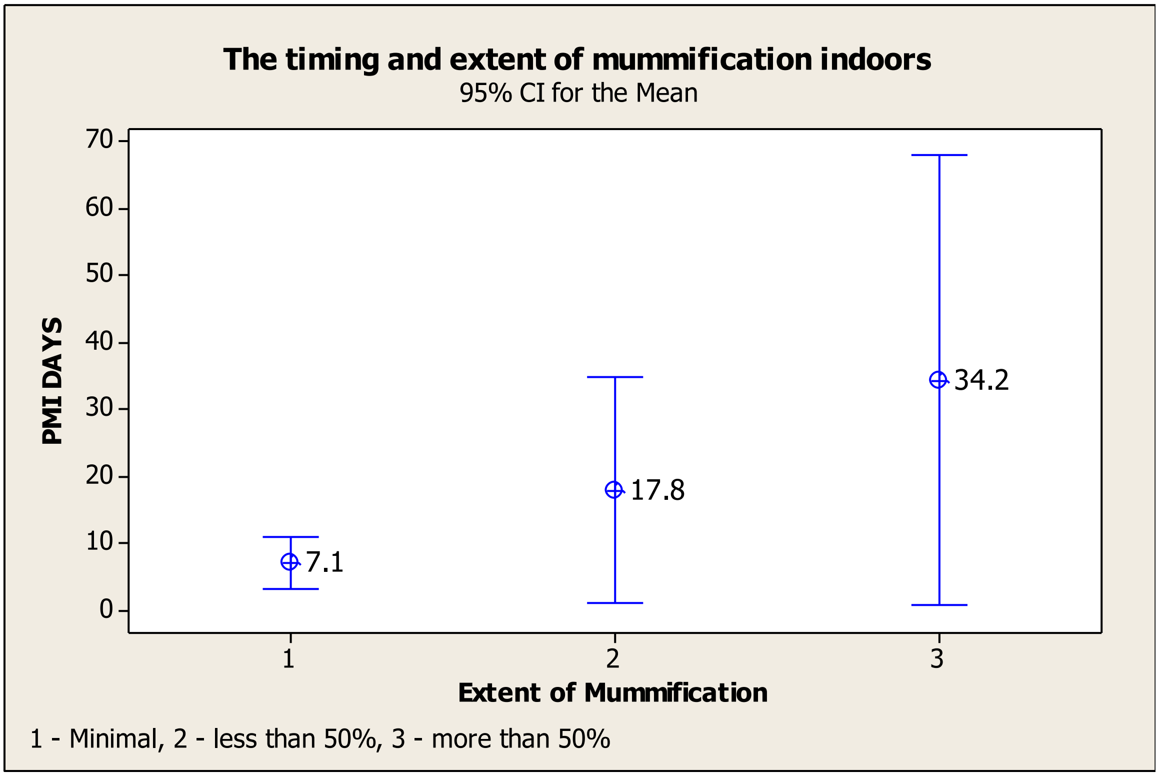


Figure 4.34. ***The mean PMI in days is shown for the progression of mummification indoors. For the Canadian dataset, it takes on average 7 days to see a minimum amount of mummification. For mummification of more than 50% of the tissue, it takes on average 34 days. There is an increasing error rate with the increased extent of mummification. N=193***

Table 4.9. ***The frequency and extent of mummification at each stage of decomposition indoors.***

Stage of Decomposition	No. Of Cases	Level 1 small portion	Level 2 Less than 1/2	Level 3 more than 1/2	Level 4 total
0	54	0	0	0	0
1	90	2	2	0	0
2	13	1	1	0	0
3	14	2	1	0	0
4	6	1	3	0	0
5	15	1	4	0	1
6	1	0	1	0	0

Note: stages 7 & 8 not present in indoor dataset

The Impact of Seasonality on Decomposition Indoors

The assumption is that temperatures are generally constant indoor year round with the use of air conditioners and central heating systems; however the impact of the seasonal variability in outdoor temperatures has been examined on the progress of decomposition for indoors cases.

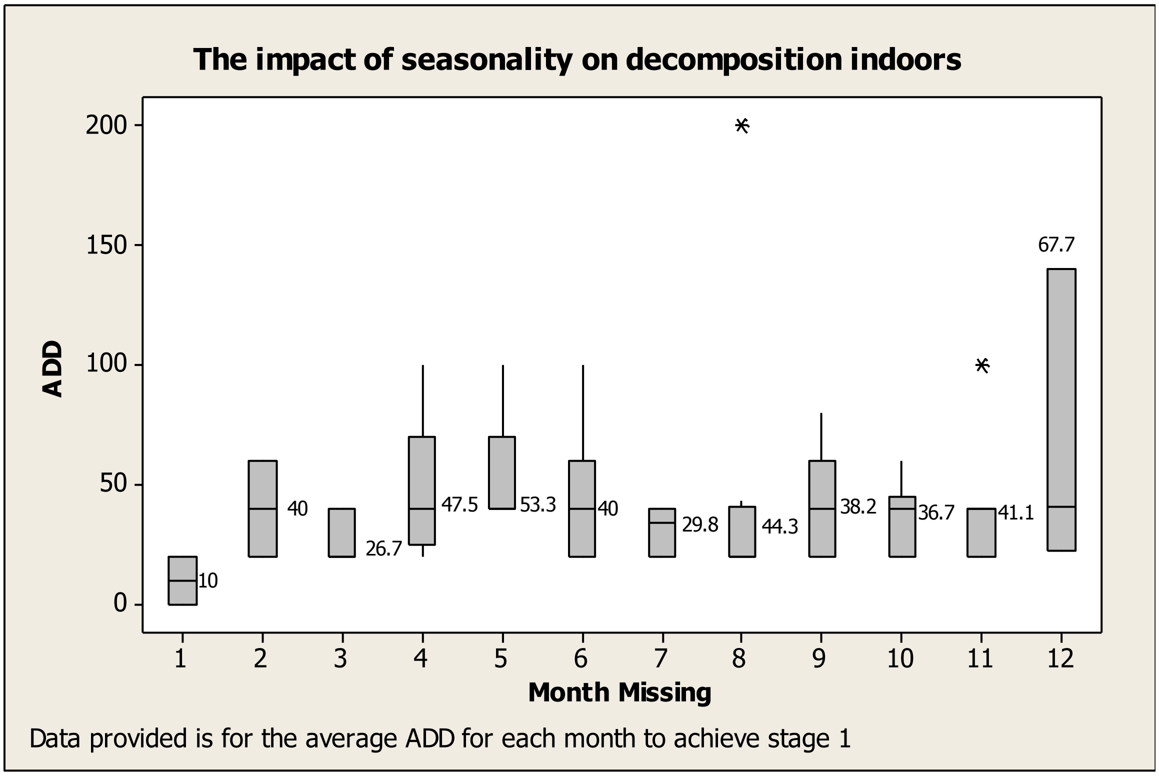


Figure 4.35. The indoor dataset has been divided into months of the year (1 represents January and 12 December). The cases were sorted into month groups based on the time of the year the individual died (was last seen). The mean ADD score has been provided for stage 1 decomposition for each group for comparison purposes. The results show what the mean ADD scores are very similar for all months of the year. The smallest ADD score (the fastest) was actually found in January and the longest (the slowest) found in December. Seasonality does not have a dramatic impact on the ADD scores for decomposition indoors.

There is only a slight range in the mean ADD score between all twelve months of the year (Figure 4.35) for the cases to achieve stage 1 decomposition. Although the accumulation of temperature is arbitrary for indoor cases, the accumulation of temperature by days is variable for stage 1. It takes a similar amount of time in February compared to August to achieve stage 1 indoors.

4.1.4. *The Normal Progression of Human Decomposition in Water*

The cases in the water represent one of the smallest samples of cases in this study with only 27 cases; all with a PMI of one year or less. The ADD score for these cases was calculated in relation to the ambient temperature as opposed to the temperature of the water, which was generally unknown. The assumption was made that the bodies spent at least part of the post mortem interval exposed to the ambient air. The variability in the PMI days has been provided (Figure 4.36) for each case at each stage of decomposition.

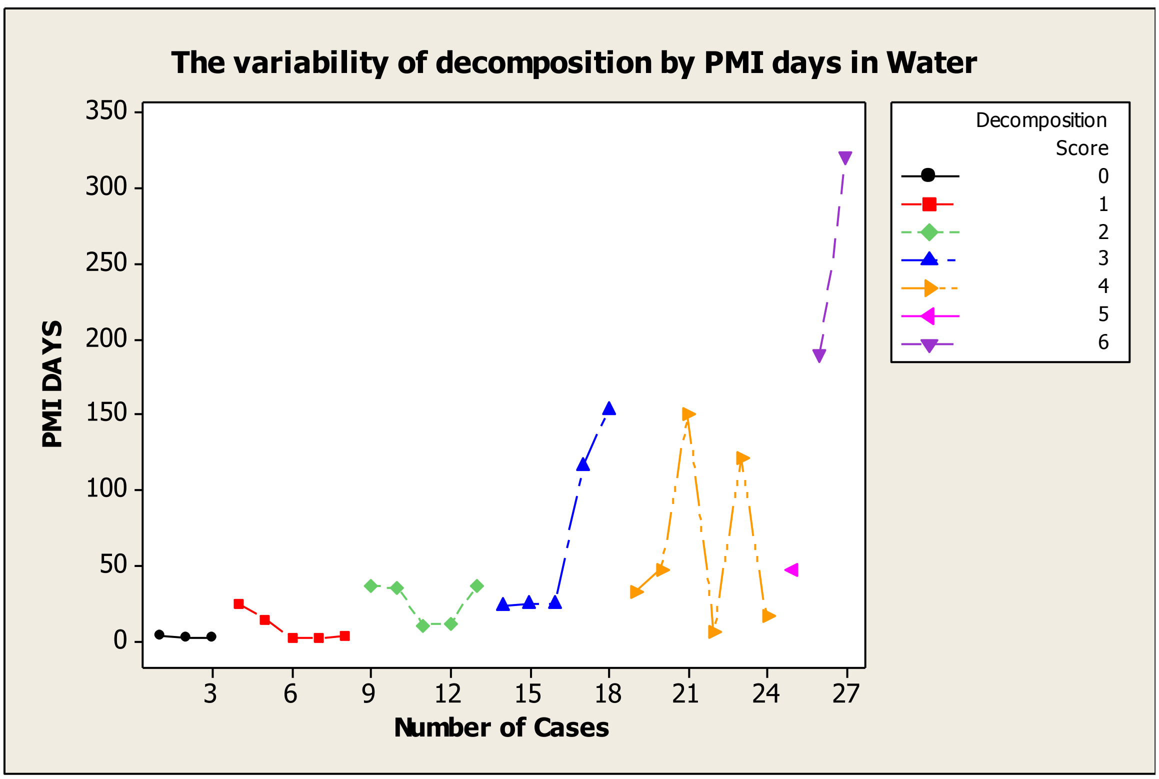


Figure 4.36. The variability in the time it takes to achieve each stage of decomposition in water. Each of the shapes represents one case. Stages 0 to 2 shows a relatively limited time range with increased variability for stages 3 to 6. This data shows that the stages of autolysis are relatively predictable; however the onset of putrefaction (stage 3) shows a distinct increase in variability. N=27.

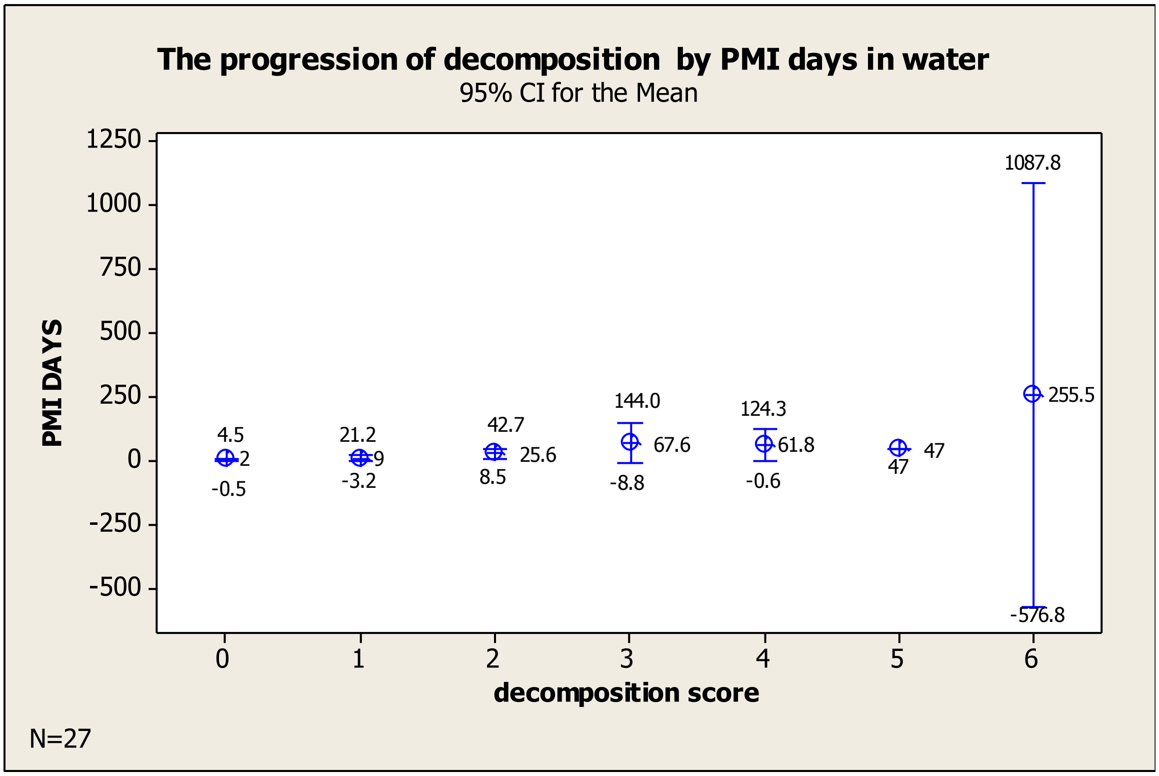


Figure 4.37. ***The mean PMI days is provided for each stage of decomposition of the bodies recovered from water. There is only one case at stage 5 and no cases at stage 7 and 8. This data shows relatively small error rates for stage 0 to 2 with an increased error rate for stages 3 and 4. Stage 6 has the largest error rate which represents the onset of skeletonization. N=27***

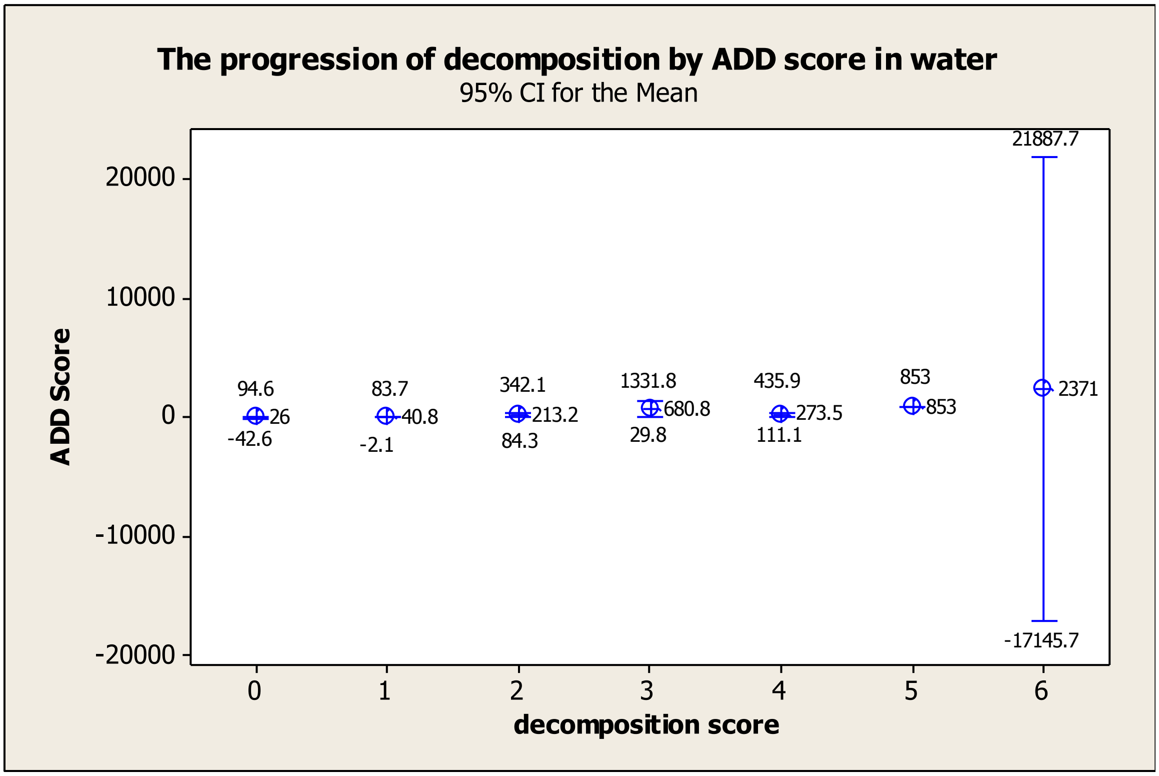


Figure 4.38. ***The mean ADD score is provided for each stage of decomposition for bodies recovered from water. There is only one case at stage 5 and stages 7 and 8 are not represented. There is an increased variability at stage 3 and 4. These results show a large error rate for stage 6 decomposition which is the onset of skeletonization. N=27.***

The mean ADD score and PMI days for each stage of decomposition in the water have been provided (Figures 4.37 and 4.38). The 95% confidence interval for each stage of decomposition was also shown. The increasing variability in time with the increasing stages of decomposition was similar to the pattern demonstrated in all other scene types. The onset of putrefaction (stage 3), had an increase in variability compared to the earlier stages of decomposition.

The following is the qualitative and quantitative analysis of decomposition in water environments. These cases include not only those in outdoor environments, but those individuals who have died inside submerged or partially submerged in water indoors in a bathtub. Due to the very small sample size, compared to the indoor and outdoor dataset, caution is urged when looking at "average" ADD scores and PMI days estimates.

Stage 0

Stage 0 is the period immediately after death when there are no visible signs of decomposition. This is considered the 'fresh' state. There are three cases with stage 0 decomposition. All three were in a river in the Ottawa, Ontario area during the winter months with relatively low ambient temperatures. The average ADD for this stage is 26. The 95% confidence interval for the ADD score is from a maximum of 94.6 to -42.6. The average PMI is 2 days. The 95% confidence interval for PMI is from 4.5 days to zero.

Stage 1

Stage 1 decomposition represents the visible signs of decomposition. The first sign of decomposition is generally lividity.

Figure 4.39. Lividity on the upper thigh of this individual has been caused by the constriction of their clothing, in this case a tight pair of jeans.

The lividity is generally dictated by the clothing in floating bodies as opposed to gravity. However gravity can still play a part in establishing the early position of individual in the water if the body is in a relatively stable and static position after death. Note the fixed lividity impression of the individual's blue jeans in Figure 4.39 on the upper thigh area. The scale is placed adjacent to a bruise, not an area of lividity.

There are five cases with stage 1 decomposition in the water data set. The average ADD score for stage 1 is 40.8. The 95% confidence interval for the ADD score is from 83.7 at a maximum and -2.1 at a minimum. The average PMI for stage 1 is 9 days. The 95% confidence interval for PMI is from zero to 21.2 days at a maximum.

Stage 2

Stage 2 decomposition is the first onset of tissue changes with skin slippage (Figure 4.40), hair or nail loss and marbling in the veins and arteries.

Figure 4.40. Skin slippage, or separation of the epidermis and dermis, is seen on the torso of this individual who was found in water.

There are 5 cases with stage 2 decomposition in the water data set. The average ADD score for stage 2 is 213.2. The 95% confidence interval for the ADD score is from 342.1 to 84.3. The average PMI for stage 2 is 25.6 days. The 95% confidence interval for PMI days in the water group is from 42.7 to 8.5 days.

Stage 3

Stage 3 represents the onset of putrefaction. This stage is recognized by the colour changes to both the blood and tissue. The blood takes on a greenish tinge and the tissue will take on a greenish to blue or yellow colour (Figure 4.41). This stage is also associated with the onset of bloating.

Figure 4.41. Yellow and blue discolouration is visible on the torso

There are five cases with stage 3 decomposition in the water data set. The average ADD for stage 3 water is 680.8. The 95% confidence interval for the ADD score is 1331.8 at a maximum and 435.9 at a minimum. The average PMI for stage 3 in water is 67.6 days. The 95% confidence interval for the PMI is from zero to 144 days at a maximum.

Stage 4

Stage 4 decomposition is characterized by a purple discolouration of the blood and a reddish colour to the tissue. This stage is also associated with full distension and purge fluids. There are 6 cases in this stage of decomposition in the water dataset. The average ADD score for stage 4 is 273.5. The 95% confidence interval for the ADD score is from 435.9 to 111.1. The average PMI for stage 4 in water is 61.8 days. The 95% confidence interval for PMI is from zero to a maximum of 124.8 days.

Figure 4.42. A predominantly red discolouration is visible in combination with tissue distension in the area of the face.

The discolouration of the individual shown in Figure 4.42 is distinctly red as is seen on the chest and head. Skin slippage is visible on the chest area and the presence of bloat is seen in the facial features.

Stage 5

Stage 5 decomposition represents the end stage of putrefaction. The tissue and blood generally have a brown to black colour. This stage is also characterized by the loss of gasses or post bloat putrefaction. There is only 1 individual with stage 5 decomposition. This case had an ADD score of 853 with a PMI of 47 days.

Figure 4.43. The colour of the tissue is predominantly black and brown with loss of tissue cohesion. There may be desiccation of the tissue which was exposed to the air.

Stage 5 decomposition is generally associated with a black discolouration and a lack of underlying tissue cohesion (Figure 4.43). This represents the onset of liquefaction. The tissue on these individuals is very fragile with a slightly harder desiccated exterior and a soft interior.

Stage 6

Stage 6 is the onset of skeletonization with less than 50% of the bone exposed. There are two cases in this group, both of them with adipocere formation. The formation of adipocere in water in the Canadian dataset will be discussed in the next section. The average ADD for stage 6 decomposition in water is 2371. The 95% confidence interval is from 21887.7 to a minimum of -17145.7. The average PMI for stage 6 for these two cases is 255.2 days. The 95% confidence interval for PMI is from 1087.8 days to zero.

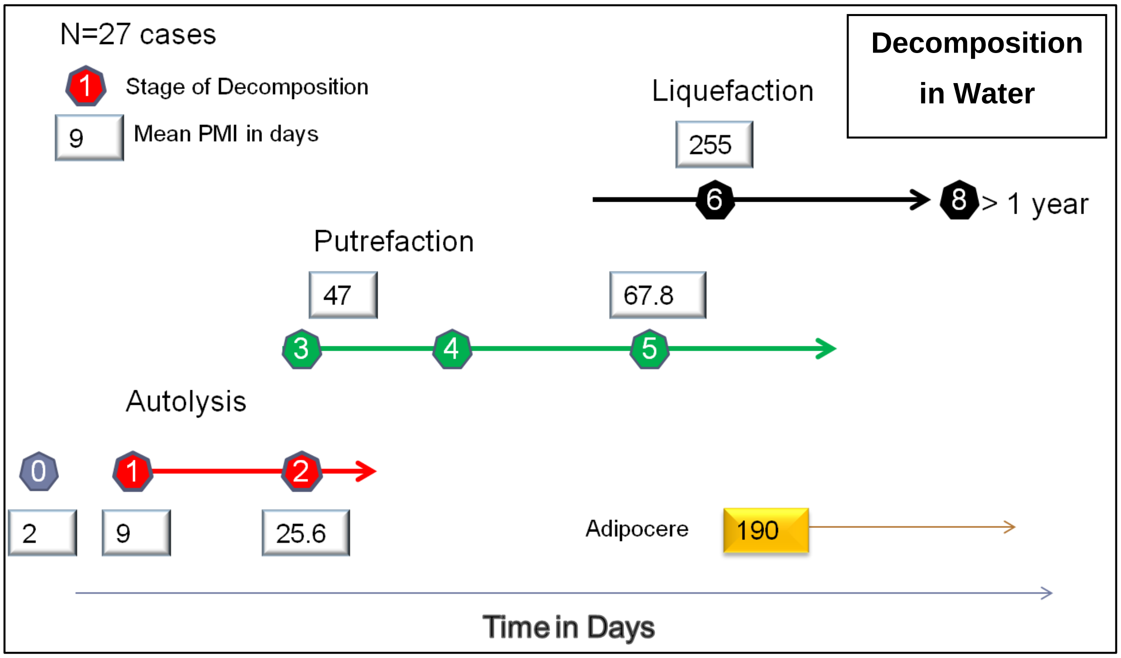


Figure 4.44. ***The progression of decomposition by PMI days in water scenes. The numbers in the coloured octagons (blue, red, green and black) represent the stage of decomposition. The blue octagon represents stage 0 – no visible signs of decomposition. The red arrow represents autolysis, green putrefaction and black liquefaction and skeletonization. The numbers in the square boxes next to the octagons is the mean PMI in days for that stage of decomposition. The number in the yellow box represents the earliest onset of adipocere in the water environment.***

The summary of PMI days for each stage of decomposition in water has been provided (Figure 4.44). There is a temporal overlap in the progression of autolysis, putrefaction and liquefaction. The onset of adipocere is provided in the yellow box for the earliest development of adipocere in PMI days.

Alternate stages of decomposition in water - Adipocere

Adipocere is the chemical transformation of body fat into a hydrolysed waxy compound not dissimilar to soap. There are only two cases in the Canadian data set with adipocere formation in water. Table 4.10 provides all of the relevant information of the four cases with adipocere formation in buried environments and the two from water.

Table 4.10. Adipocere Formation: Data for all cases in dataset (357 cases)

Case	Location	PMI Days	ADD Temp	Precip mm	Average Temp 1st Month˚C	context	Month missing	Month Found
34	Yukon	421	8420	n/a	20	Buried	March	May
69	BC	223	1034	279	14	Buried	August	April
70	BC	190	833.6	163.6	9	River	September	April
184	BC	321	3907.2	1145.6	7.5	River	October	December
199	ONT	154	2767.6	410	13	Buried	May	October
358	BC	3297	34637.2	17406	2.3	Buried	January	January

The minimum amount of time taken for adipocere formation in this dataset is 190 days for a child caught in fishing net in a large fast flowing river (Figure 4.45). The other adipocere case with a water environment involved an individual who went into a glacial fed fast flowing river as the result of a bridge wash-out. The individual was encased in his vehicle under a large amount of rock for 321 days. The average outdoor temperature for the first month of the post mortem period was 7.5 degrees Celsius however the temperature of the water during this period was likely much colder.

Figure 4.45. Adipocere formation in a water context. This individual has considerable adipocere formation after being caught in a fishing net in a fast flowing river after 190 days.

Of the four cases with adipocere formation from a buried context, the minimal time for development was 154 days. All of these individuals were fully clothed or wrapped in a breathable shroud such as a sheet or blanket. The average temperature for the first month of the decomposition period is relatively low at 12.3°C. Adipocere formation appears to be a relatively rare phenomenon in Canada.

4.2. The Qualitative or Quantitative Difference in the Progression of Decomposition Occurring Outside, Inside, Buried and in Water?

A comparison of the mean ADD score and PMI for each stage of decomposition was conducted between the scene types (Table 4.11). Not all stages are represented for all scenes (0.00 represents a stage without a case). These results have demonstrated that there is an increase in variability in the ADD score and PMI in days with the increase in the decomposition score. The largest increase in variability has been associated to the onset and progression of putrefaction (stages 3 to 5).

Table 4.11. Comparison of mean PMI days for each stage of decomposition by scene type

Stage of Decomposition	Outdoor	Indoor	Buried	Water
0	3.0	2.1	3.0	2.0
1	4.1	2.1	2.3	9.0
2	10.2	3.2	0.0	25.6
3	9.0	6.9	11.0	67.6
4	17.0	10.4	0.0	61.8
5	15.8	26.2	153.0	47.0
6	109.8	0.0	160.2	255.5
7	137.4	0.0	88.5	0.0
8	0.0	0.0	238.5	0.0

Note: The “0.00” represents stages with no cases for that scene type

The relative time it takes for bodies to proceed through the first stages of decomposition, autolysis is equivalent from one scene type to another. The scene type with the fastest onset of putrefaction is the indoor scenes with 6.9 days. The onset of putrefaction for water scenes takes considerably more time with a mean PMI in days of 47 to 67.6 days. The onset of putrefaction with buried bodies is only slightly longer than indoor and outdoor scenes. For this dataset, cases did not reach the stages of skeletonization indoor. The cases indoors showed an increased frequency and earlier presence of mummification compared to outdoors cases. Bodies in burial environments were the only ones to fully skeletonise less than one year PMI. A *t*-test analysis was conducted for the differences in the mean PMI days between the different scene types. It was determined that these differences were not statistically significant.

There are qualitative differences in the progression of decomposition between the four scene types. These differences are more noticeable during the later stages of decomposition. For the outdoor scenes, the end stages of decomposition are characterized by blackened desiccated remnant tissue adhered to exposed bone. In the burial context, the late stages of decomposition are characterized by a brown coloured wet appearance to the tissue. For bodies in the later stages of decomposition indoors, epidermal bullae can occur depending on humidity levels. Bodies indoors tend to mummify which stabilizes the soft tissue and prevents liquefaction and bone exposure. In water skin slippage is common with a reddish tissue discolouration in the later stages. Any exposed tissues will desiccate and blacken.

4.3. Part II – The Variables Which Affect Decomposition in Canada

The progression of decomposition is generally quantified in the literature by the accumulation of time or temperature. Both time and temperature were used in this study to quantify the differences in decomposition between indoor outdoor, water or burials scenes. The two predictive variables of time (PMI days) and temperature (ADD score) were analysed to determine which one had the most potential to predict change in the decomposition stage for cases in Canada. A comparison was made between the results of this study for the predictive potential of the ADD score, to the results of the study by Megyesi et al. (2005).

The qualitative progression of human decomposition consists of the visible changes which occur to the body during the process of decomposition. Due to a variety of environmental and contextual differences, a body decomposing in one scene type may look different compared to another from a different context. The intent of the qualitative analysis was to determine if there were distinguishing differences in the visible stages of decomposition between the four contexts.

4.3.1. *The Comparison of the ADD Score and PMI as a Predictive Variables for the Decomposition Score*

Simple least square linear regression analysis was conducted to compare the correlation between ADD and PMI and the progression of the decomposition score for all indoor cases (Figure 4.46), and outdoor cases (Figure 4.47) with one year PMI or less. The R^2 values for both ADD and PMI were less than 50% for both indoor and outdoor scene types. The outliers were removed for the outdoor cases (Figure 4.48) to produce slightly better correlation of R^2=53% for ADD and R^2=41% for PMI in days.

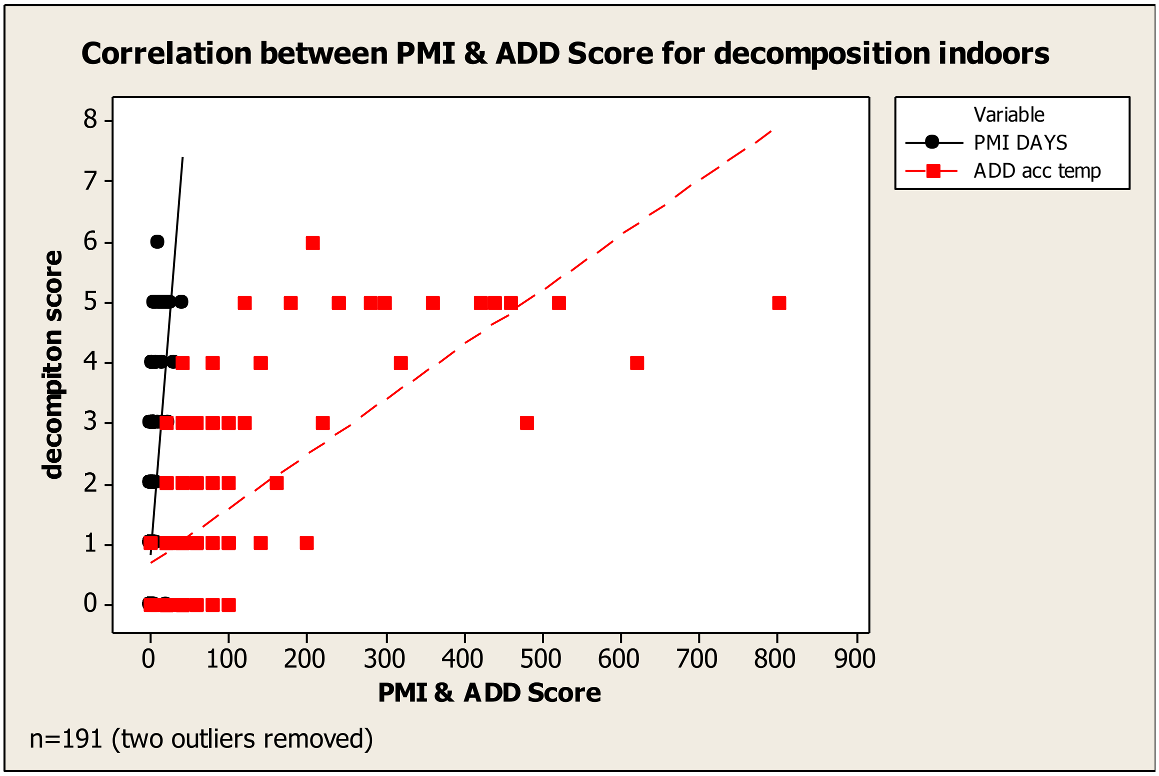


Figure 4.46. ***Comparison of the correlation of ADD in days and the PMI score to the change in the decomposition score for indoor cases less than one year PMI. ADD is R-Sq=48.8% and PMI is R^2=45.3%. The results show a better predictive ability for the ADD score versus the PMI days. However, the predictive ability for either variable is low at less than 50%. N=191.***

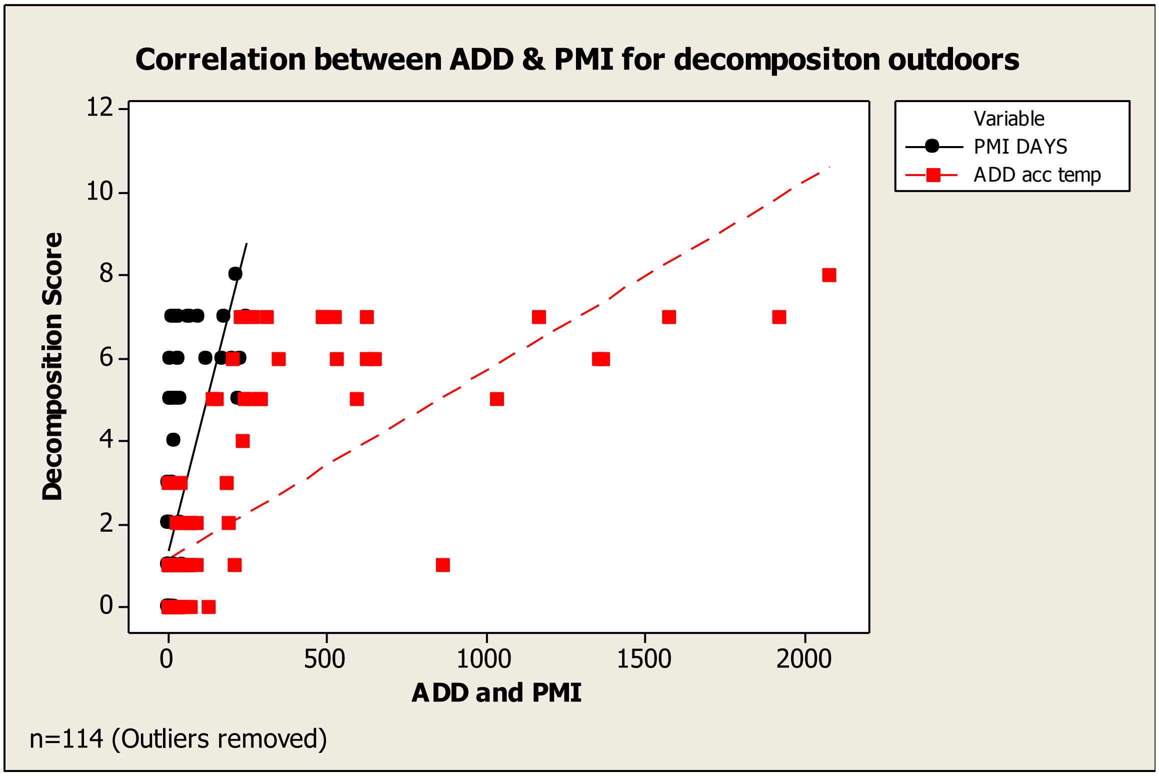


Figure 4.47. ***Comparison of the correlation between the ADD score and PMI in days for the change in the decomposition score for Outdoor cases N=114. The correlation for the ADD score is R^2=53.0% and PMI in days is R^2=41.4%. Seven outliers were removed from the analysis. The correlation results for both predictive variables are low, however the results for the ADD score is better compared to the PMI in days.***

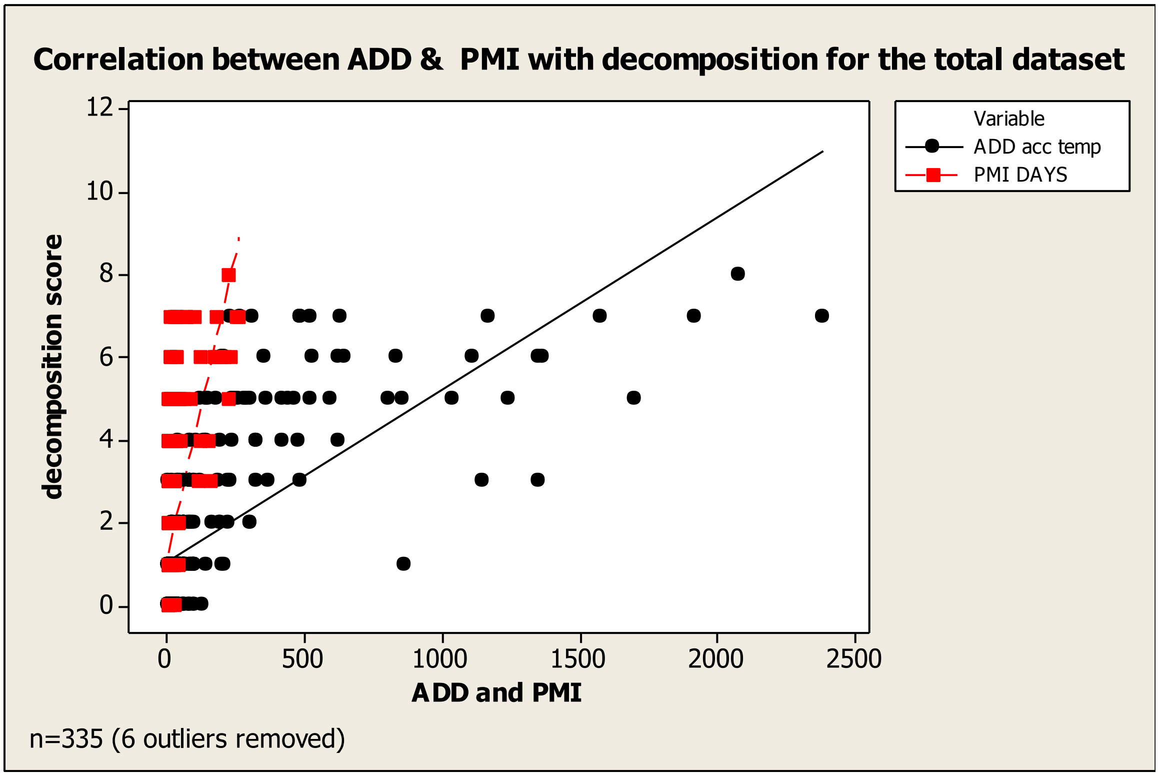


Figure 4.48. ***Comparison of correlation of ADD and PMI for the change in the decomposition score for the entire data set under one year PMI (six outliers were removed). ADD is R^2=47.5% and PMI is R^2=37.3%. There is a better correlation between the ADD score and decomposition compared to the PMI in days, however the overall predictive ability of either variable is low at under 50%.***

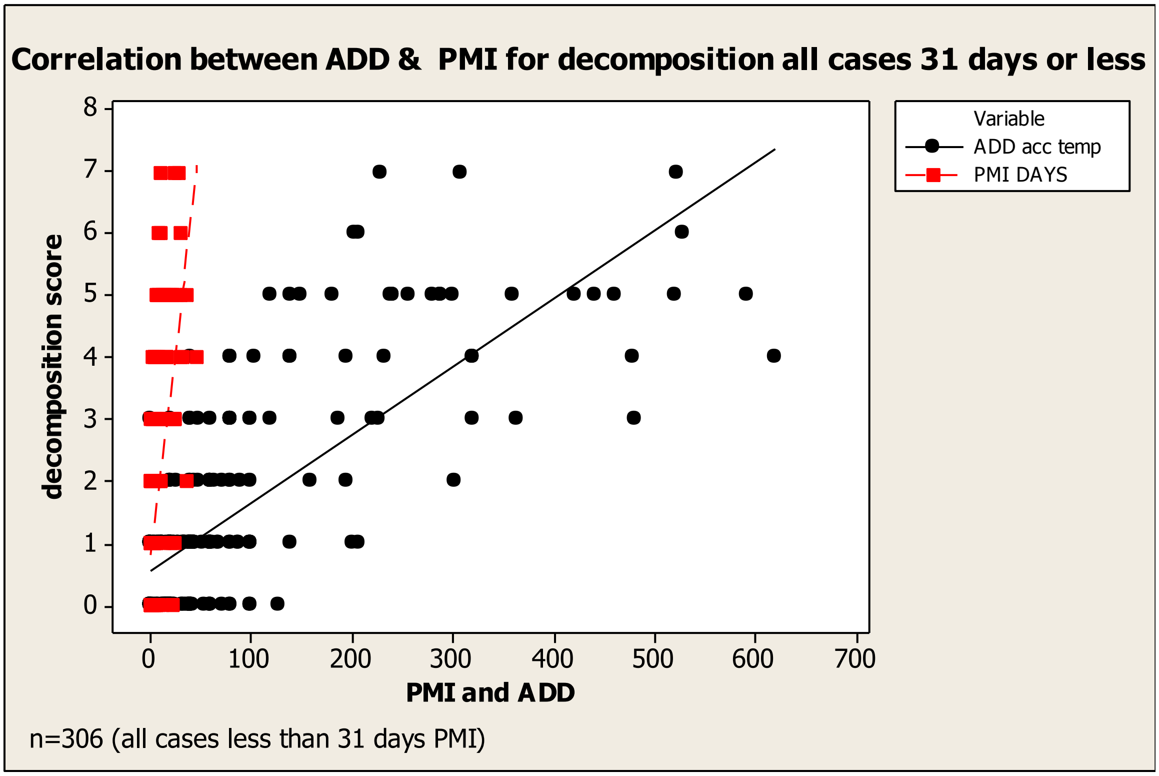


Figure 4.49. Comparison of the correlation of the ADD score and PMI in days for the change in the decomposition score for all cases in the data set (n=306) with a PMI of 31 days or less. ADD is R^2=56.7% and PMI is R^2=40.5%. The limitation of the PMI time period did not result in a large improvement in the correlation between either variable to predict the change in the decomposition score for this set of cases.

The results of the analysis conducted for the combined dataset with a PMI of one year or less with outliers removed (Figure 4.48 & 49) did not result in a large improvement in the ability of either variable to predict the change in the decomposition score. The correlation for both variables for the entire dataset regardless of scene type resulted in a maximum of 57% for the ADD score and 40% for the PMI in days. A time period of 31 days was used to determine if there was a difference in the ability of either variable to predict change in the earlier, as opposed to later stages of decomposition. The results for the analysis of the cases with a PMI of 31 days or less resulted in a correlation of R^2=56.7% for the ADD score compared R^2=47.5% for the PMI in days.

Correlation analysis was also conducted for the entire dataset (N=341) and the outdoor dataset (N=121) without the removal of outliers. The scatter plot charts for this analysis has not been provided, however the results have been provided in Table 4.12.

For comparison purposes, the results of all regression analysis have been provided for all datasets used in Table 4.12.

Table 4.12. A summary of the ADD and PMI regression results for variability in the decomposition score for scene types and time periods.

R^2 %	Indoor <1 yr N= 191	Outdoor <1 yr N=121	Outdoor <1 yr N=114*	All <1 yr N=341	All <1 yr N=335*	All ≤ 31 days N=306
ADD Score	48.8%	43.1%	53%	39.1%	47.5%	56.7%
PMI Days	45.3%	44.8%	41.4%	38.3%	37.3%	40.5%

Note: * Outliers in this group were removed. The R^2 percentage represents the % of variability in the decomposition score that either the accumulated temperature (ADD) or accumulated time (PMI) represents.

The highest level of correlation for the ADD score was achieved in the total dataset (all environments) for a PMI of 31 days or less resulting with R^2=56.7%. There was a 10 to 15% difference in the predictive potential of either the PMI in days or the ADD score for the total dataset group with a PMI of 1 year or 31 days or less. When several of the outlier cases were removed from the outdoor set (N=114), the correlation of the ADD score to the change in decomposition increased, however the PMI in days correlation decreased.

4.3.2. *Comparison of Results with the Study by Megyesi et al., 2005*

The study by Megyesi et al. (2005) compared the ADD score to the variability in the decomposition for their dataset of 66 cases from the United States. The study found that the ADD score had the ability to predict 85% of the variability in the change to the decomposition score versus 72% for the PMI in days. The results this study produced a maximum correlation 57% for the ADD score to predict the changes in the decomposition score for 306 cases from all scene types with a PMI of 1 year or less (Table 4.1). The largest correlation result for PMI days and the decomposition score for any dataset in the study was 45% (Table 4.12).

Further analysis of the data from this study has been conducted to investigate the potential explanations for the discrepancy between the results of this study and those of Megyesi et al. (2005). The methodology used by Megyesi et al. (2005) was to conduct a log transformation of the linear regression between the ADD score and the Total Body Score (TBS). The TBS is a slightly different classification system which scores body elements to produce a cumulative score of the level of total body decomposition. Although the numbers used for the scoring system are different, the cumulative nature of both classification systems is comparable.

A log10 transformation was conducted for the correlation between the ADD score and decomposition for all scene types in the study with a PMI of 1 year or less (Figure 4.50).

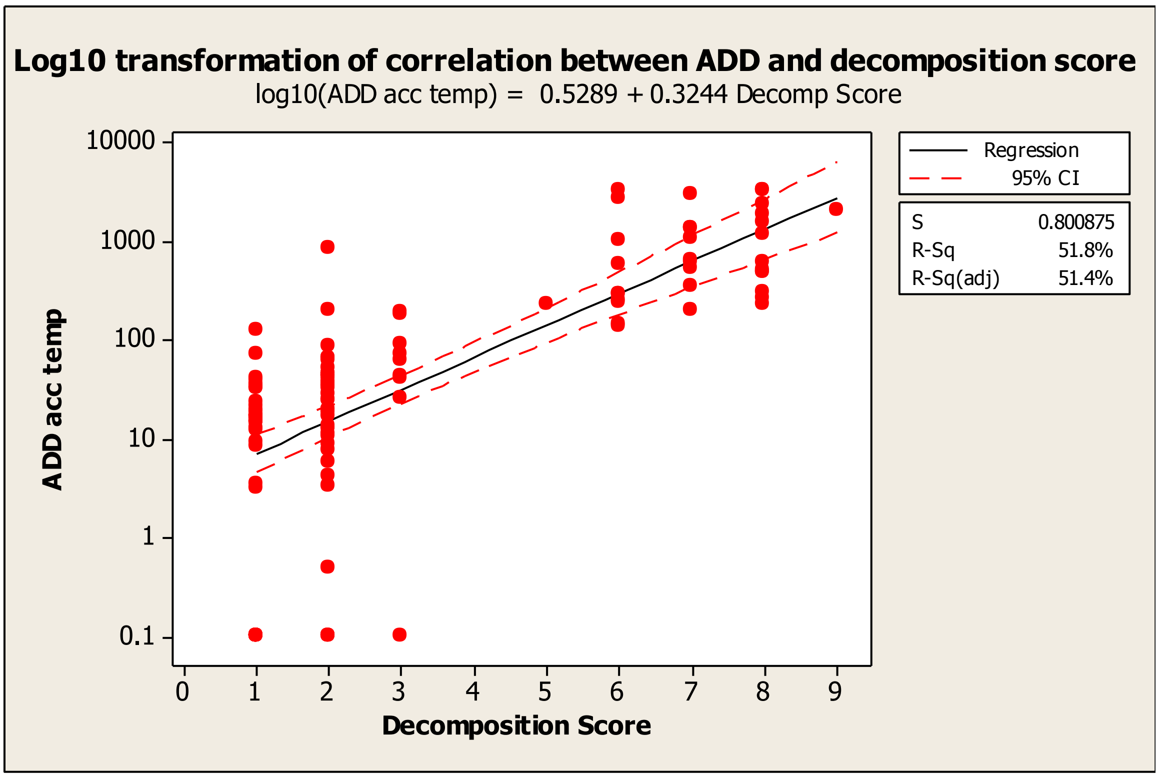


Figure 4.50. A log10 transformation was conducted of the lineal regression for the ADD and decomposition score for the outdoor set of cases 1 year PMI or less (N=121). The log10 transformation produced a correlation of R^2(adj) of 51.4%. The transformation increased the correlation from 43% for the simple least square regression analysis (Table 4.10).

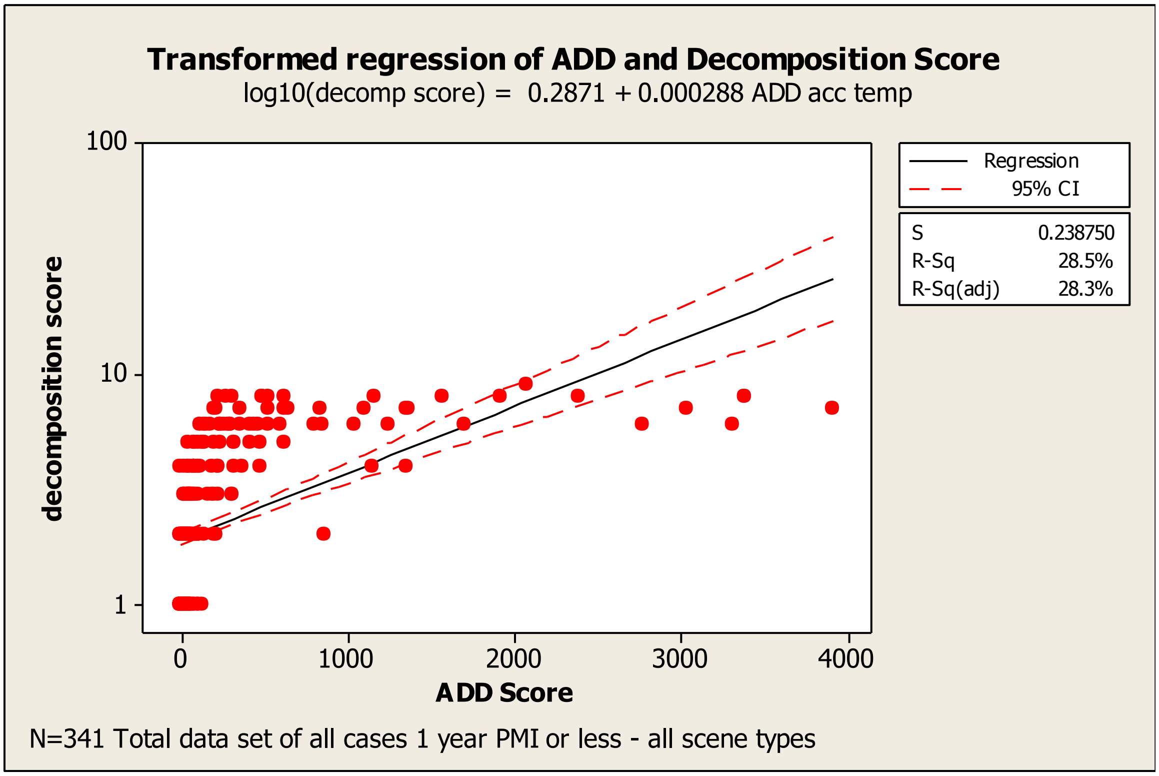


Figure 4.51. ***log10 transformation of the fitted line for ADD and the decomposition score for all the cases with 1 year PMI or less (N=341). The result is a correlation of R^2(adj)= 28.3%. The result of the simple regression analysis for ADD and the decomposition score for this dataset was R^2 = 39.1% (Table 4.1).***

The transformation of the regression line did not achieve the same level of results produced by the Megyesi et al. study (2005). The least squares simple regression analysis for the outdoor group with 1 year PMI or less (N=121) produced a result of R^2=43.1% for the ADD score related to the variability of decomposition (Table 4. 10). The log10 transformed fitted regression line (Figure 4.51) for the same group produced a slightly better correlation of R^2(adj)=51.4%. There was an improvement in the results for the outdoor group, however a 51% correlation does not support the ADD score as being the single most important predictor in the change in the decomposition score for outdoors scenes in Canada.

For the total data set, the least squares regression for the ADD score for all cases produced a result of R^2=39.1% (Table 4.1). The log10 transformation of the regression line of ADD and the decomposition score for all cases 1 year PMI or less (Figure 4.2), produced an even lower correlation of R^2(adj)=28.3%. These results suggest that the ADD score as an independent variable, does not explain the majority of the variability in decomposition regardless of the scene type within this Canadian dataset.

The results of the study by Megyesi et al.'s (2005) study have not been replicated by this study. The highest level of predictive potential for the ADD score in the Canadian dataset was 57% compared to the 85% for Megyesi et al.'s (2005) study. Even though this study did not use the same decompositional scoring system (TBS) for decomposition in the Canadian cases, both classification system used a numeral interval scale of increasing value which made the two classification systems comparable. The cases used for both studies were from a range of scene types and geographical regions. The sample size used for this study was substantially larger with 355 cases compared to 66 cases for the Megyesi et al. (2005) study.

4.3.3. ***The frequency and distribution of RLDV by scene type***

The ADD scores were used to calculate a RLDV for each case as described in the methodology section 3.6.2. Figure 4.52 provides the results of the frequency in RLDVs for each major scene type. For this analysis the buried scene type is included in the outdoor dataset.

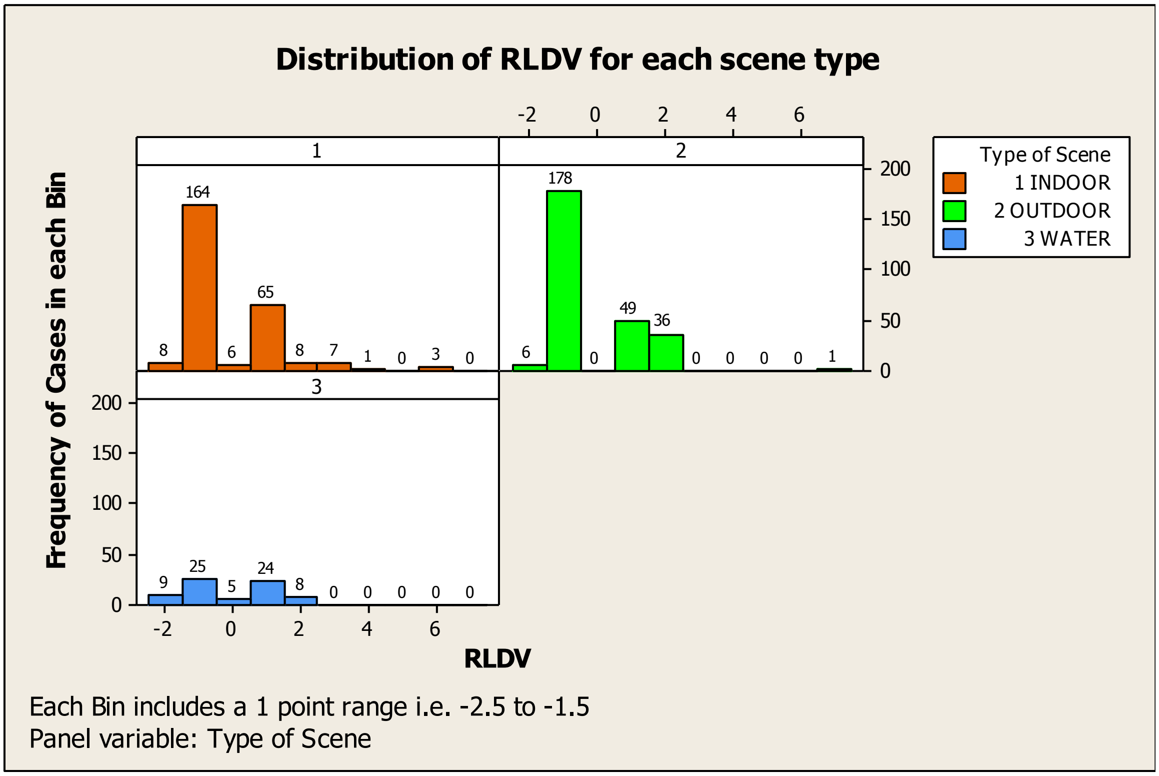


Figure 4.52. ***The frequency of RLDVs for each indoor, outdoor and water scene types. The zero represents a mean ADD score for that case. None of the cases in the outdoor scenes had an exact mean score. There is a very small sample size of water cases (N=27). For the other two scene types the distribution in RLDV appears similar for indoor and outdoor scene types. There is a higher frequency of cases in both sets with a -1 value. This distribution has likely been affected by the inclusion of outliers in the calculation. The highest frequency of RLD values for these two scene types is slightly less than the mean and is scored a -1. A negative score suggest a slightly faster rate of decomposition.***

The frequency of RLDV for each scene type is focused on the negative side of the scale in both the indoor and outdoor scenes (Figure 4.52). The larger amount of cases on the negative side of the scale is likely due to the skewing effect of the large ADD scores (outliers) in the original calculation of the mean for each stage of decomposition in each scene type. Taking into consideration the skewing effect, the distribution of positive and negative RLDV appears to be normal. This is most evident with the water cases. Most of the cases are within 2 standard deviations from the mean with several outliers in the inside and outside dataset. The outliers occur on the positive as opposed to negative side of the scale which suggests that these cases have lingered in a stage of decomposition of a period of time as opposed to reaching that stage unusually early.

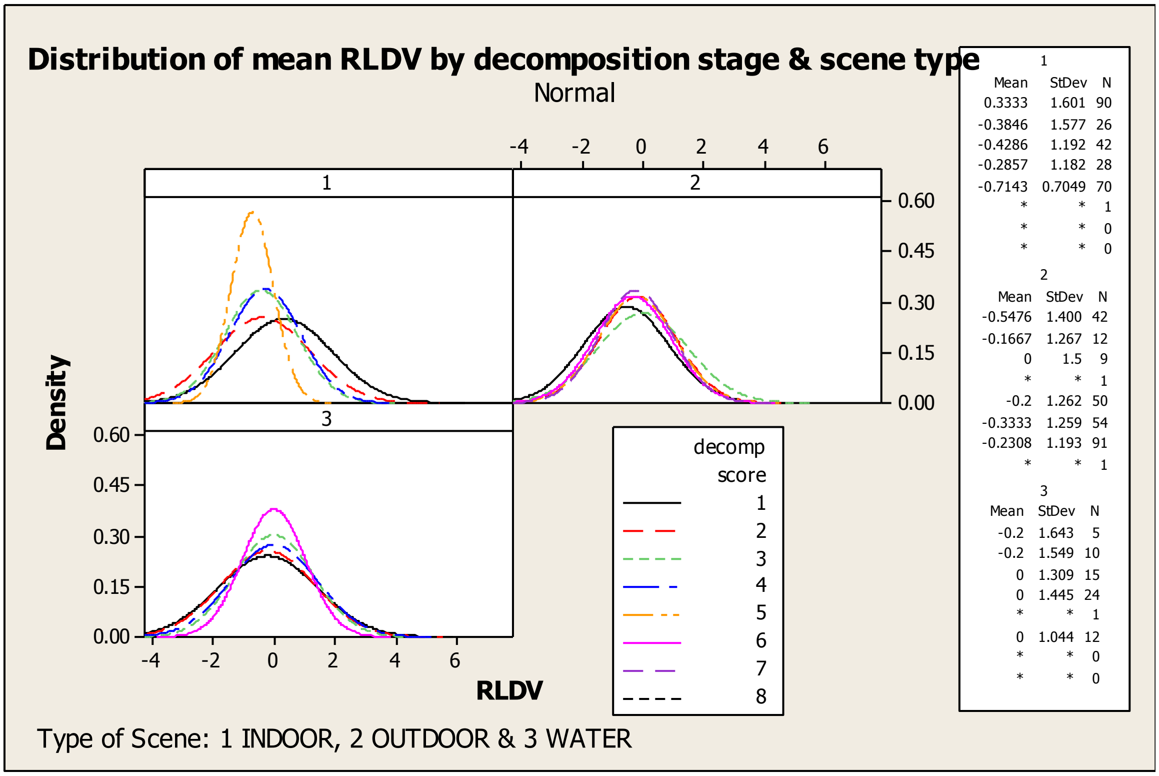


Figure 4.53. The curve distribution of mean RLDVs for each scene type: water, indoor and outdoor groups by stages of decomposition. The indoor distribution shows a slant towards the negative end of the scale for stage 5 decomposition (putrefaction). The results for each stage of decomposition outdoor show a normal curve.

The distribution of the mean RLDV is provided for each stage of decomposition by indoor, outdoor or water scene types (Figure 4.53). The results for the indoor scene type shows stage five decomposition with an anomalously steep curve oriented on the negative end of the scale. The pattern of negative and positive values in the outdoor and indoor data sets does appear to be different with more variability in the results for indoor cases compared to the outdoor cases. The results for the water cases appear to have normal distributions, however should be treated with caution due to the small sample size.

4.3.4. *The Independent Variables which have an Impact on the Variability of Decomposition Inside, Outside, in Burial or in Water*

There are a number of variables which have the potential to impact the progression of decomposition in any scene context. The number and type of variables vary by scene context. The environmental, immediate context and intrinsic variables have been examined for the four scene types. The impact of the amount of precipitation and extremes in temperature has been examined as potential predictive variables for decomposition outdoors. The variables which impact the immediate context of the body such as extent of clothing or shrouds, sun exposure, level of insects and scavenging have also been evaluated as potential predictive variables. Age, sex, body size, manner and cause of death, type of trauma, extent of blood loss and alcohol and drug consumption are some of the intrinsic variables evaluated as part of the study.

Environmental Variables

Due to the biochemical nature of the processes of decomposition, the accumulation of temperature correlated in an advancement of the stages of decomposition. It is unknown what impact a period of cold or freezing temperatures has on the continuing progression of decomposition. It is assumed that extremes in temperature will negatively affect the biological process which facilitates human decomposition by denaturing the bacterial or enzymes and effectively suspending or retarding the progress of decomposition.

Impact of Cold Temperatures on Decomposition Outdoors in Canada

All cases in the outdoor set with a minimum temperature of 4 degree Celsius or less were selected to compare the progression of decomposition for cases exposed to cold versus warmer temperatures. The temperature of 4 degrees Celsius was selected as the normal refrigerator temperature threshold where bacterial growth is severely retarded (Micozzi 1997:172). A total of 69 cases or 57% of the outdoor case were found to fall below the 4 degrees Celsius temperature threshold. Two outliers were removed from the analysis. The regression analysis of the ADD score and PMI in days for decomposition for the ‘cold’ group was comparable to the results produced by the ‘warmer’ group. The regression analysis for the ADD score vs. decomposition for the cold group resulted in R^2=49.1%; the correlation with the PMI days is R^2=48.1% (Figure 4.54). The results for the ADD score are comparable for those found in the larger outdoor data set with R^2= 53% or less. The PMI correlation with decomposition for the cold group is slightly higher with a 3% increase of the best correlation found within the larger outdoor group.

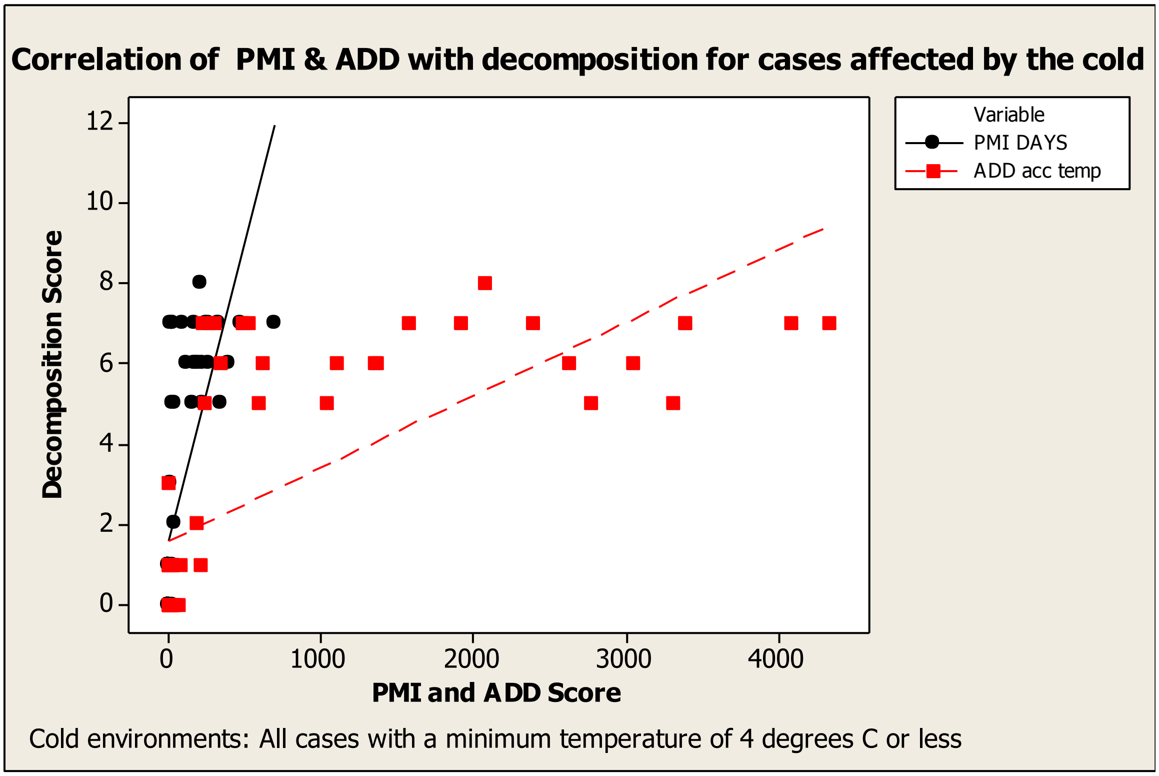


Figure 4.54. ***The correlation between the ADD score, PMI days, and the decomposition score for cases with a minimum temperature of 4 degrees Celsius or less in the outdoor group. N=67. The results show a low level of correlation for temperature (ADD score) at R^2= 49.1% and time (PMI days) at R^2=48.1%. These results are lower than the correlation results for the larger dataset with all cases.***

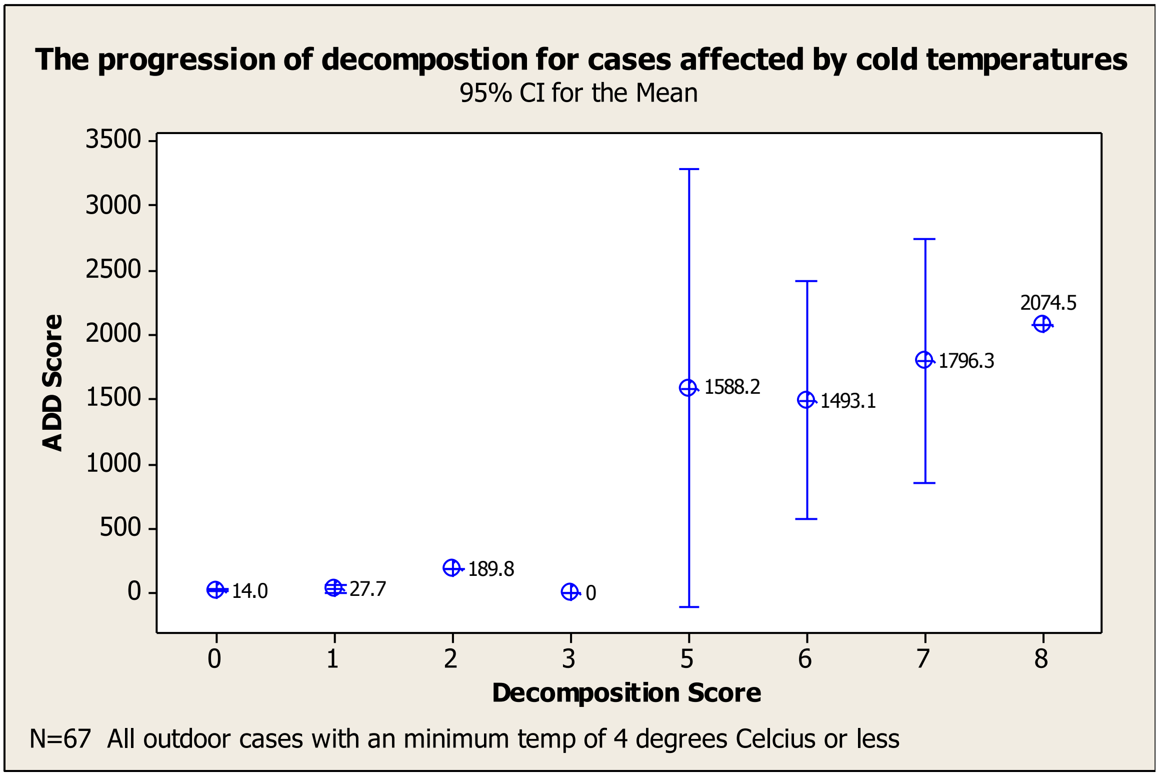


Figure 4.55. ***The mean ADD score is provided for each stage of decomposition with an associated 95% confidence interval. This dataset includes all cases outdoors that had a minimum temperature of 4 degrees Celsius or less during the PMI. There is considerable variability in the ADD scores for the late stages of putrefaction and onset of skeletonization for this group. N=67***

A comparison was made between the mean ADD scores and PMI in days for each stage of decomposition for the 'cold' compared to the 'warmer' group (Figures 4.55 and 4.56). The results of the comparison demonstrated the same overall pattern of ADD score variability with the increasing stage of decomposition; Stages 0 to 4 had a much smaller error range compared to stages 5 and higher. Stages 0, 2 and 4 had a lower ADD score in the 'cold' group compared to the 'warmer' group which suggested that it took less temperature to reach that stage of decomposition in cases with colder environments. The later stages of decomposition in the 'cold' group consistently took a larger ADD score on average to achieve stages 5 to 8 decomposition. Colder temperatures did not appear to impact the earlier stages of decomposition but did retard putrefaction and skeletonization in stages 4 to 8.

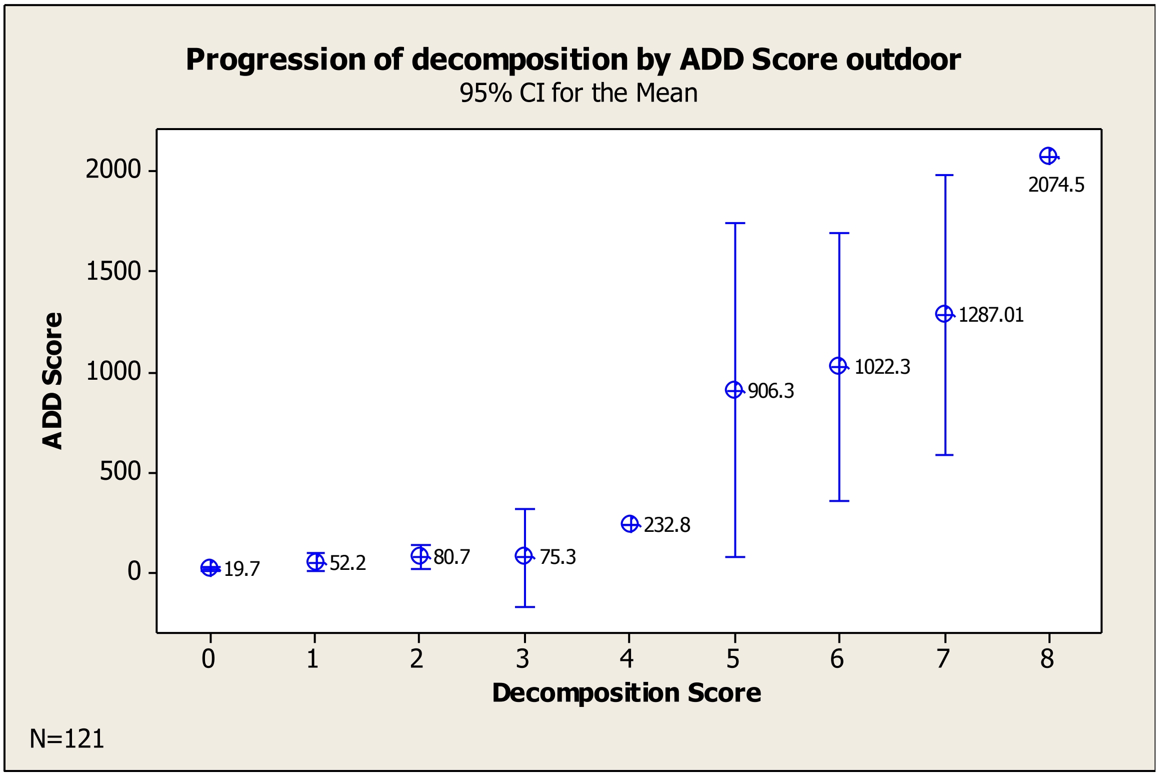


Figure 4.56. ***The mean ADD score with a 95% confidence interval for each stage of decomposition for the outdoor dataset (n=121). This dataset includes all cases exposed to a range of temperatures. The confidence intervals increase with the increase in the stages of decomposition.***

During the colder seasons in Canada, there is the potential that several days may pass without contributing any positive temperatures to the ADD score. Therefore, the variable of time was examined with this 'cold' dataset to determine whether or not it took more time to decompose compared to the rest of the outdoor group. The progression of decomposition in PMI days was calculated for the total outdoor group (Figure 4.58) to be compared to the 'cold' group (Figure 4.57).

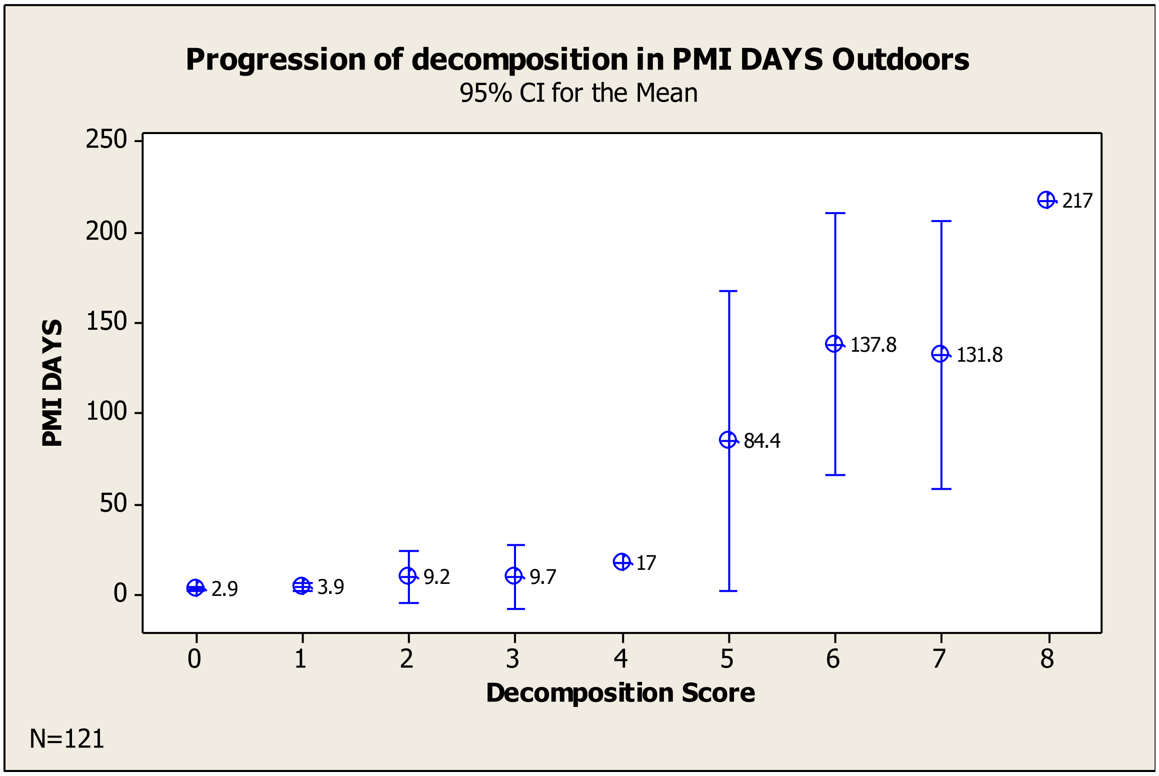


Figure 4.57. The mean PMI days and associated confidence interval for each stage of decomposition for the entire outdoor cases.

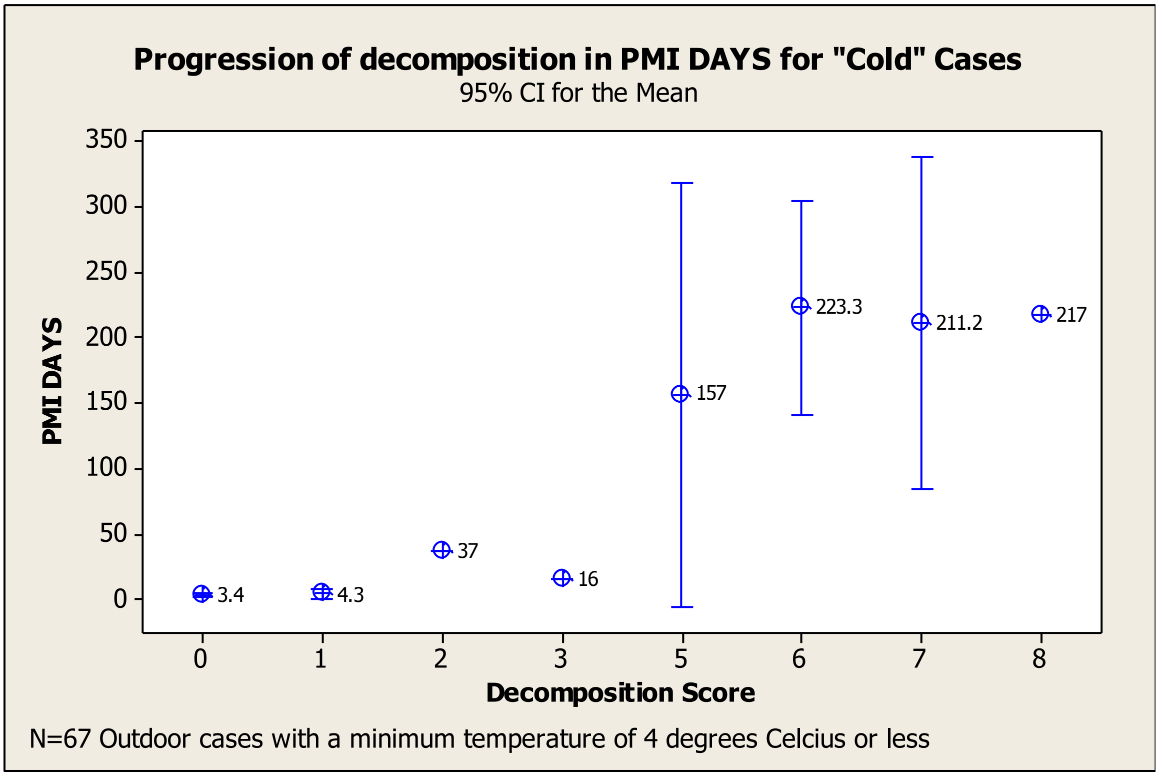


Figure 4.58. ***The mean PMI days for each stage of decomposition with a 95% confidence interval. This group includes 67 cases with a minimum temperature of 4 degrees Celsius or less from the outdoor group. Compared to the results for the total dataset (Figure 4.57), it took considerably more time to reach stage 5 for the cold group. The variability in the PMI days for stages 5 to 7 show that this group has a higher likelihood to linger at the late stages of putrefaction and early stages of skeletonization compared to the normal group.***

When the PMI of the ‘cold’ group is compared to the total outdoor group, the ‘cold’ group takes consistently more time to reach each stage of decomposition compared to the bigger outdoor group. Based on these results, cold temperatures do have a quantifiable affect on the time a body takes to decompose. In relation to the ADD scores, it takes less temperature to achieve the first stages of decomposition from stage 0 to 4 but it takes more temperature to reach the later stages of putrefaction and skeletonization.

The Impact of Precipitation on Decomposition Outdoors

Moisture has been identified by many taphonomy researchers as a potentially significant predictive variable for the progression of decomposition (Table 2.7). Water is the source of hydrogen for biochemical cellular reactions and affects the dilution of chemical concentrations on either side of the cell wall. The body acts as a source of moisture for the growth of mycota, bacteria and plants. Without sufficient moisture the hydrolase enzymes are not able to break down biological polymers (carbohydrate, lipids and proteins). Gill-King (1997) suggests that a low moisture environment will retard the rate of decomposition and a high moisture environment will promote soponification with large amounts of lipids.

The total accumulation of precipitation (rain and snow) was calculated for the post mortem period. The cases in this study received a range of total precipitation depending on the length of the post mortem interval, the season, geographical location and deposition of the body, either indoors or out (Figure 4.59). The group within no precipitation (45%) also included the indoor cases. Of the remaining scenes, the majority of the cases (43%) experienced between 1 and 50 mm of precipitation during the post mortem interval.

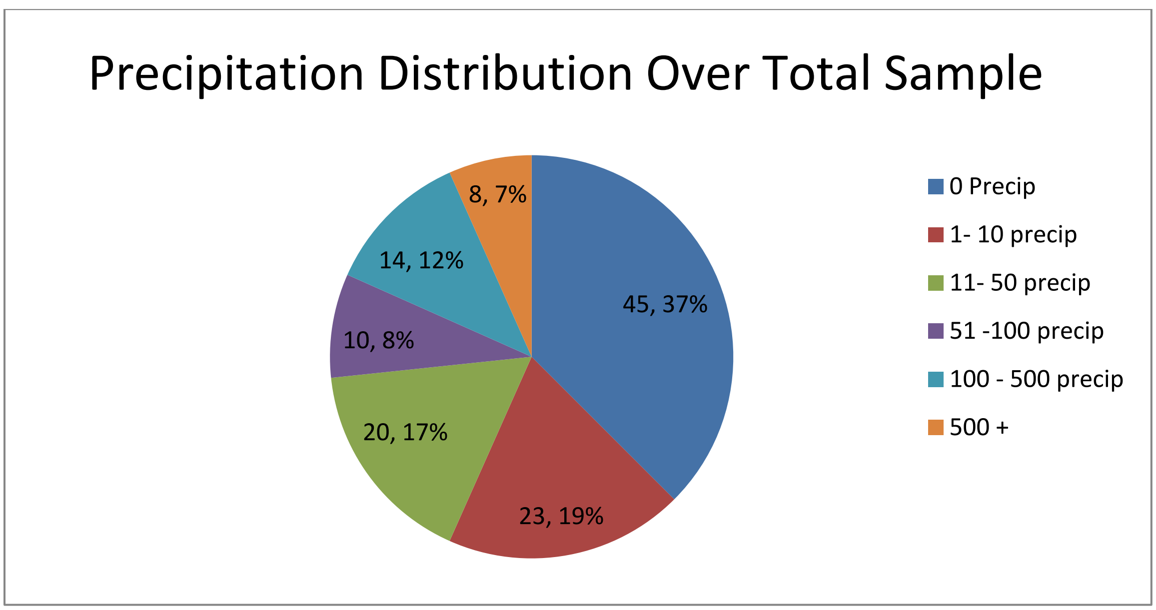


Figure 4.59.   The percentage of cases that experienced a range of total precipitation during the PMI. The majority of the bodies outdoor were exposed to between 1 and 10 mm of precipitation during the PMI. The longer the post mortem interval, the more the body is exposed to precipitation. N=358

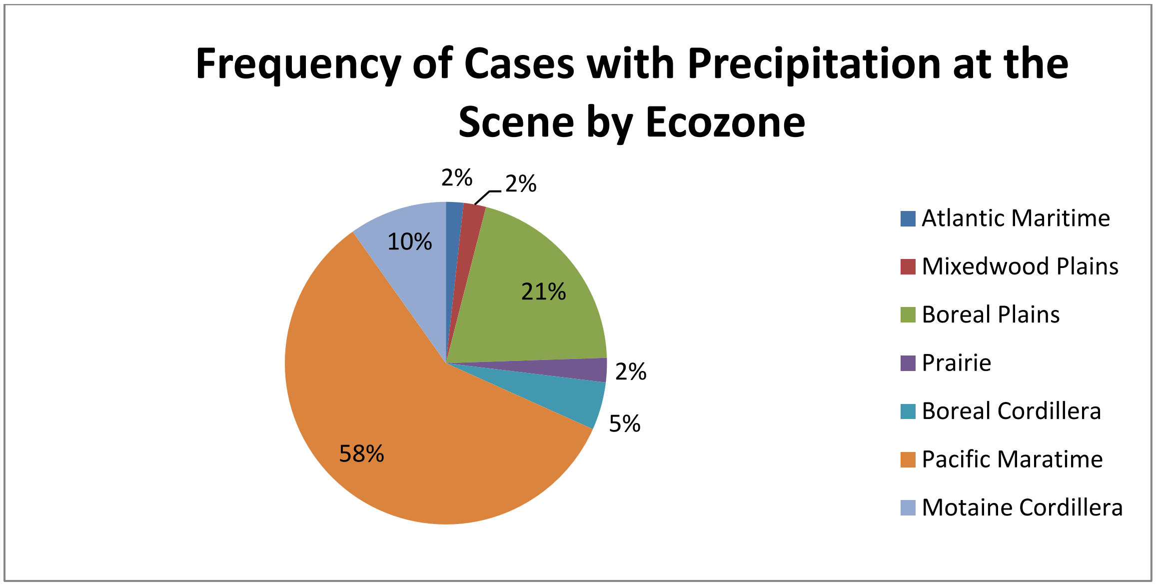


Figure 4.60. The average amount of precipitation that a body is exposed to during the PMI is provided by ecozone. Scenes in the pacific maritime ecozone, which is the temperate rain forest, had the highest amount of precipitation at 58%.

The average amount of precipitation that a body was exposed to during their PMI was calculated for each ecozone (Figure 4.60). As expected the cases in the Pacific maritime ecozone on the west coast of Canada demonstrated the highest levels of precipitation at 58% of all of the recorded precipitation. The ecozones with the smallest amount of precipitation was the mixed wood plains and the Atlantic Maritimes with 2% each.

Table 4.13. Correlation between ADD score & precipitation with the decomposition score

Correlations: Decomposition Score, Total Precipitation & ADD Score		
	Decomposition Score	**Total Precipitation**
Total Precipitation	0.509	
ADD Score	0.657	0.851

Note: results provided in a Pearson correlation P-Value number

The correlation coefficient assumes a value between -1 and +1. If one variable tends to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together the correlation coefficient is positive. Independently the correlation of the ADD score to the decomposition stage is

P=0.657 and with precipitation as a variable; P=0.509. The combined variables of temperature and precipitation had a P-value correlation of 0.851 which is not significant (Table 4.13).

Table 4.14. Stepwise regression for PMI days, the ADD score and precipitation for outdoor cases with a PMI of one year or less

Stepwise Regression: Decomposition Score versus PMI & Total Precipitation

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Decomposition Score on 3 predictors, with N = 121

Step	1	2	3
Constant	1.441	1.412	1.354
PMI DAYS	0.0218	0.0296	0.0201
T-Value	9.82	6.79	3.62
P-Value	0.000	0.000	0.000
Total Precipitation		-0.0027	-0.0039
T-Value		-2.06	-2.86
P-Value		0.041	0.005
ADD acc temp			0.00150
T-Value			2.65
P-Value			0.009
S	1.90	1.88	1.83
R^2	44.76	46.68	49.70
R^2(adj)	44.30	45.78	48.42
Mallows Cp	11.5	9.0	4.0

The stepwise regression analysis examined the correlation of time, temperature and precipitation with the progression of decomposition in the outdoor scenes (Table 4.14). The combination of ADD, PMI and total precipitation accounts of 48% of the variability in the stage of decomposition within this study. The direction of the correlation with precipitation is negative which suggested that it had a negative impact on the decomposition score compared to PMI and ADD scores.

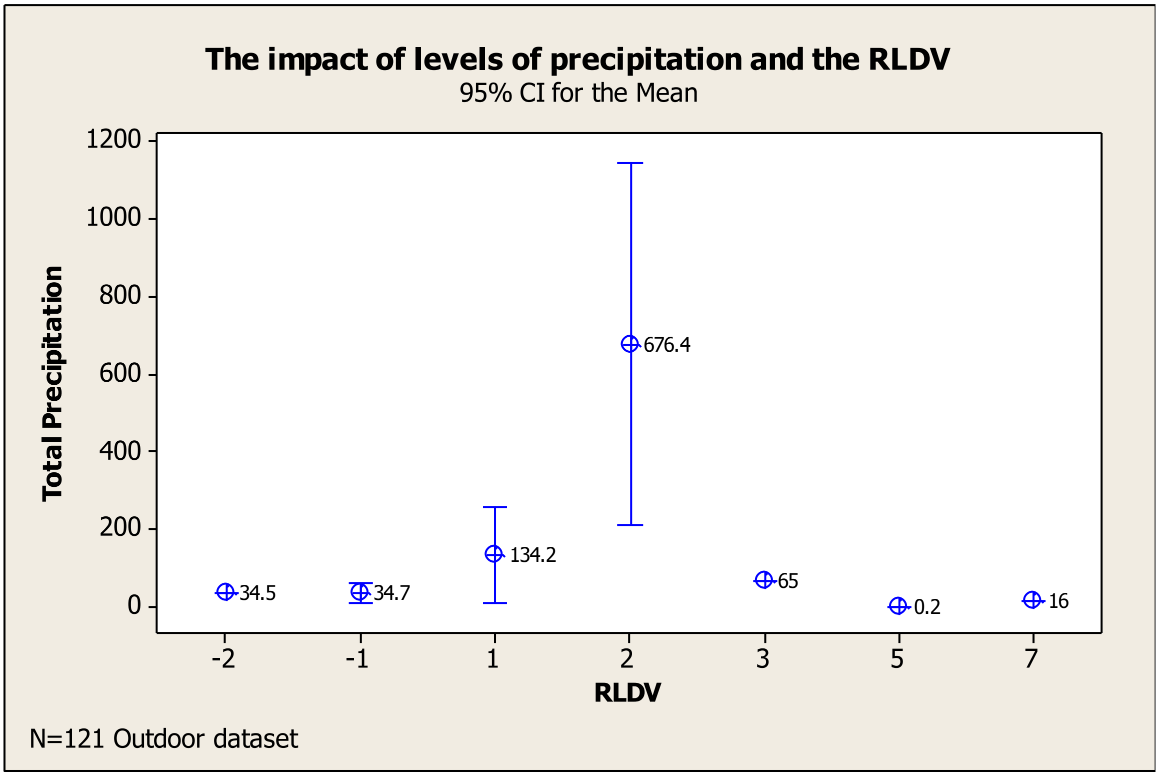


Figure 4.61. The correlation between precipitation amounts and mean RLDV for all outdoor cases. The RLDV represents the relative rate of a case with negative ratings being faster and positive being slower. The number of the RLDV is the standard deviation from the mean. There does not appear to be a relationship between the total amount of precipitation and the rate of decomposition.

Precipitation as an independent variable did not appear to have a significant impact on the progression of decomposition. The step-wise regression analysis did suggest that there may have been a negative relationship between precipitation and rate of decomposition. The impact that precipitation had to the progression of decomposition in the outdoor cases was relatively small compared to the accumulation of temperature or time. The relationship of precipitation to the stage of decomposition is negative which suggests that the increase of precipitation acted to decelerate the progression of decomposition outdoors.

Immediate Context Variables

The immediate context variables are associated with the immediate environment or context of the body. These variables may affect the decomposition on a more local level and involve variables which are not necessary constant from one scene to another give the same scene type. These variables may related to ranges in temperature, moisture, acidity or oxygen supply due the extent of clothing and coverings (shroud), surface type or impact to tissues due to the involvement of scavengers or insects. These immediate context variables may impact decomposition very differently from one scene type to another; therefore each variable has been examined separately.

At outdoor scenes, bodies will be subjected to the widest range of context variables. Some of the variables which were recorded for this study are listed in Table 4.15. Not all variables can be quantified in an ascending or descending scale in order to facilitate regressive or statistical analysis. These particular variables do not necessarily represent all of the possible extrinsic variables, but these were chosen based on the type and extent of information available during the study.

Table 4.15. The immediate context variables at outdoor scenes

Clothing	Fully clothed to Naked	
Coverings	No coverings to full shroud	Extent of debris on body
Decompositional Surface	Organic v. inorganic	Flat v. sloped
Sun Exposure	Full sun exposure to full shade	
Scavengers	minimal to extensive	
Insects	minimal to extensive	

Clothing and Shrouds

Many researchers have assumed that the extent of clothing has a quantifiable impact on the progression of decomposition (Table 2.7). Some researchers propose that clothing speeds up decomposition while others suggest decomposition is slowed down. The level of clothing was assessed in this study to determine whether or not it had any effect on the rate of decomposition, whether positive or negative. There are only four categories for clothing based on the ViCLAS classification scoring system: Fully clothed (1), exposed genitals (2), partially clothed (3) and naked (4). Shrouds are items of a range of materials from breathable to non-breathable which have been used to cover or wrap the body.

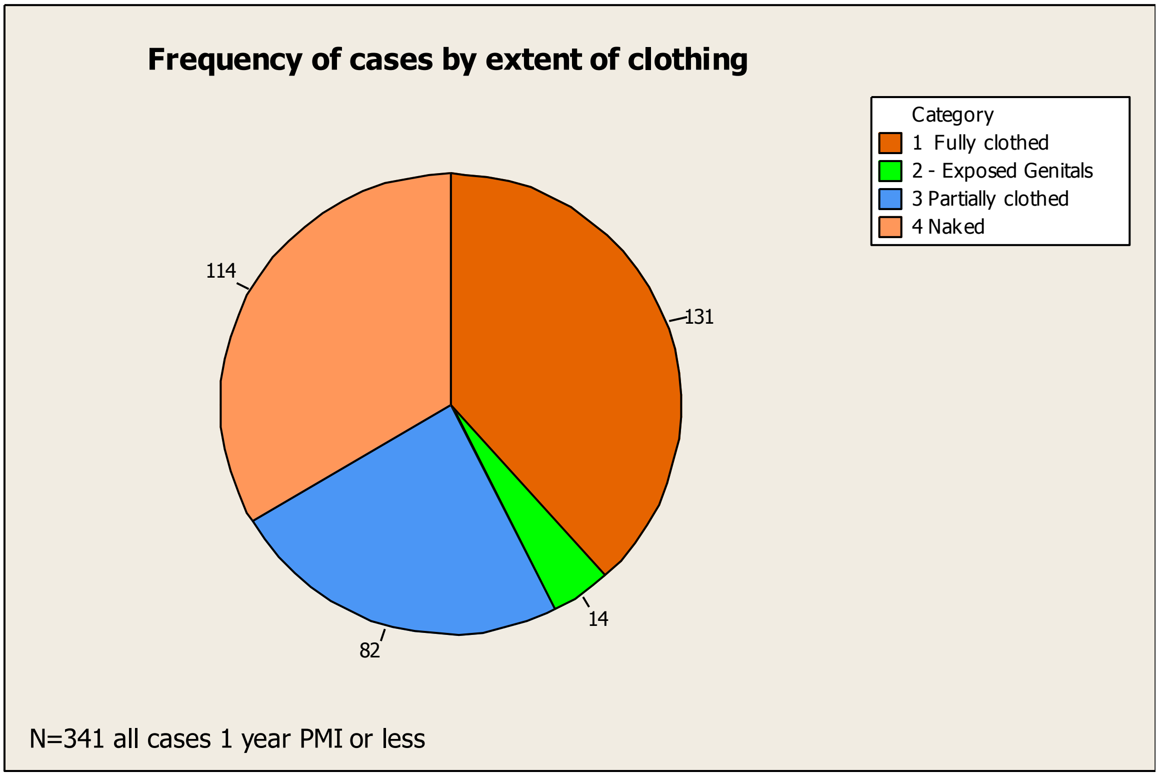


Figure 4.62. ***The frequency of cases by extent of clothing for all scene types. The majority of the cases in the study involve bodies which are fully clothed (38%). There is a large representation of bodies which are naked (33%) and partially clothed (24%). The minority of the bodies are clothed with only the genitals exposed (4%).***

This pie chart (Figure 4.62) provides the frequency of cases where the individual was discovered fully clothed, partially clothed, with exposed genitals or naked. The majority of the cases in the Canadian dataset are fully clothed (131), however there is an almost equivalent number of individuals who are totally naked (114), which provides an opportunity for comparison.

It would appear based on Table 4.16 that there is very little difference in the time it takes for a body to decompose fully clothed as opposed to one which is totally naked. The mean PMI days for each stage of decomposition for group 1 versus group 4 are very similar. However, it does appear that the naked bodies do take consistently less time to decompose on average compared to the fully clothed group.

Table 4.16. Comparison of mean PMI days the stages of decomposition by extent of clothing.

Stage of Decomposition	Total Dataset	Fully Clothed Only	Naked Only
0	2.5	2.5	2.9
1	2.9	2.4	2.0
2	9.3	15.6	13.0
3	21.0	37.1	9.1
4	32.9	42.4	39.5
5	50.3	69.0	66.4
6	146.8	175.0	150.1
7	131.8	35.7	175.6

Note: Stage 8 has been excluded. Units are in PMI days. N=341

Table 4.17. T-test for significance of the difference in PMI days between the fully clothed and naked groups

Paired T-Test and CI: Fully Clothed, Naked				
Paired T for Fully Clothed - Naked				
	N	Mean	StDev	SE Mean
Fully Clothed	8	47.5	56.1	19.9
Naked	8	57.3	69.0	24.4
Difference	8	-9.9	53.7	19.0
95% CI for mean difference: (-54.8, 35.1)				
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.52 P-Value = 0.620				

Table 4.17 is a comparison of the means between the naked and fully clothed groups using the PMI score for each stage of decomposition. This *t*-test has demonstrated that there is no significant difference (P-value = 0.62) between the two groups. Therefore, it takes relatively the same time to reach each stage of decomposition for a fully clothed body compared to one which is entirely naked. Therefore as a single variable, it does not have a significant effect on the PMI in relation to the decomposition score.

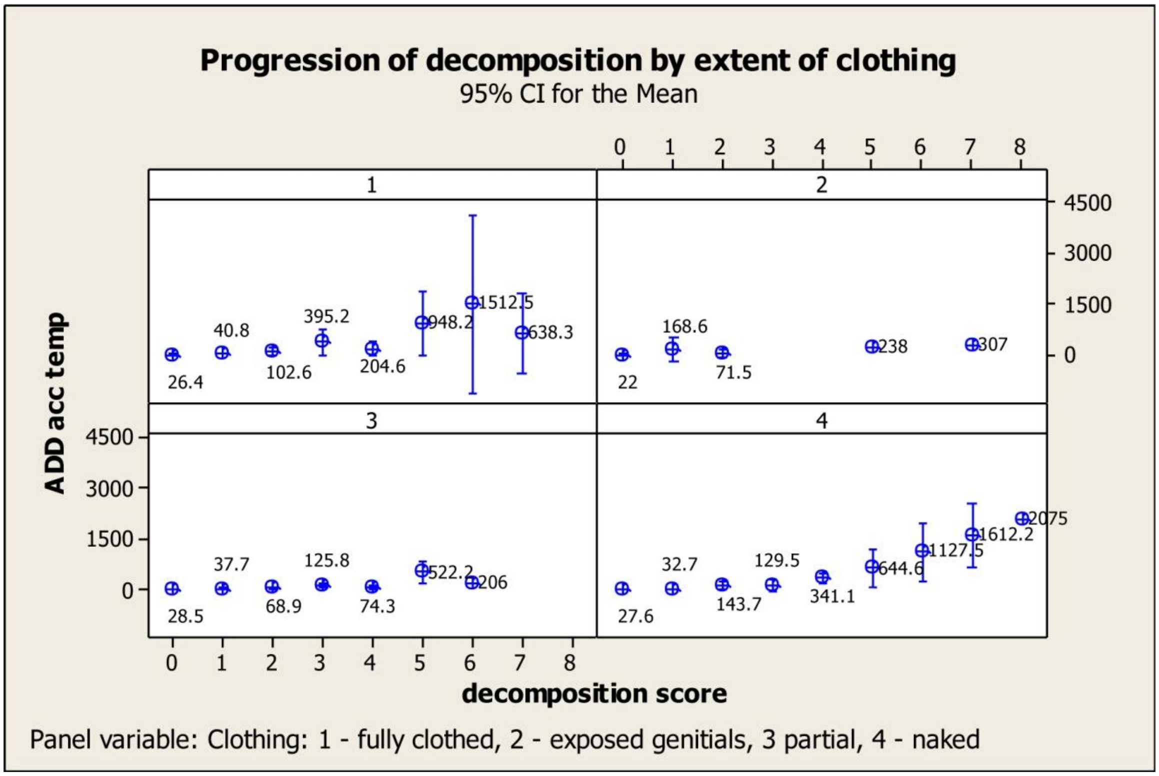


Figure 4.63. A comparison of the mean ADD scores for each stage of decomposition by level of clothing. Group number 1 is the fully clothed group number 2 exposed genitals, 3 partial and 4 naked. Due to the small numbers of cases within group 2, only a comparison between number 1, 3 and 4 is possible. There is very little difference in the mean ADD scores for each stage of decomposition regardless of the extent of clothing. N=341 entire dataset of all scene types 1 year PMI or less

Figure 4.63 compares the average temperature or ADD scores for each stage of decomposition sorted by range of clothing. Stages 3 and 5 have a larger ADD score in the fully clothed group (1) compared to the naked group (4), which suggests it takes more temperature to achieve these levels. Stages 6 to 8 have a higher ADD score for the naked group compared to the clothed group. It can be suggested therefore that it does take less time for a naked body to decompose but not necessarily less temperature.

Table 4.18. Comparison of mean ADD scores for each stage of decomposition.

Stage of Decomposition	Total Dataset	Fully Clothed Only	Naked Only
0	27.1	26.4	27.6
1	43.2	40.8	32.7
2	98.0	102.6	143.7
3	237.2	395.2	129.6
4	235.2	204.6	341.1
5	688.7	948.2	644.6
6	1179.1	1512.5	1127.5
7	1287.1	638.3	1612.2

Note: N= 341 for the total dataset 1 year PMI or less. Stage 8 has been excluded.

Table 4.19. T-Test for the ADD score for naked versus fully clothed bodies

Paired T for Fully Clothed – Naked – ADD Scores				
	N	Mean	StDev	SE Mean
Fully Clothed	8	484	526	186
Naked	8	507	583	206
Difference	8	-24	427	151
95% CI for mean difference: (-381, 333)				
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.16 P-Value = 0.879				

A paired *t*-test for the group with clothing compared to the group without (Table 4.19) found that there was no significance (P= 0.879) in the difference between clothed and unclothed bodies. Table 4.19 demonstrates that it takes relatively the same temperature to reach each stage of decomposition for a clothed body as compared to a naked one. Although clothing does not appear to have significance as an independent variable, it may have significance in a complex of variables for decomposition.

The impact on this variable in each type of scene was examined. Only within the buried context did clothing have a negative impact on the stage of decomposition. In a buried context the higher the level of clothing resulted in a slowdown in the rate of decomposition. Within the water context, it could be presumed that clothing would insulate the body from scavengers and limit the mechanical impact of water movement such as tides and contact with sides, floors of water bodies and associated debris. There is only a very small sample of bodies in water in this dataset. There are only two fully naked bodies outdoors. A comparison was made between the actual PMI and ADD scores compared to the mean scores for that level of decomposition in water and found that the results are inconclusive (Table 4.20).

Table 4.20. PMI and ADD scores for stages 2 & 4 for naked bodies in water compared the total group.

Decomposition Score	Naked group PMI	Total group Mean PMI	Naked group ADD score	Total group mean ADD score
2	36 days	25 days	301.5	190
4	150 days	190 days	415.2	273

For the naked bodies in water it seems to take more time than average and more temperature compared to the mean PMI and ADD scores for that level of decomposition in water. These results should be considered with caution due to the extremely small sample size.

Shrouds

For the purposes of this study, shrouds are defined as anything that has been placed over or wrapped around a body after death. The shrouds in this study were classified as being either breathable (2), non-breathable (4) or mixed (3). Examples of a breathable shroud would be a sleeping bag or a blanket. The non-breathable shrouds were generally consist of plastic bags. The assumption in the literature is that any kind of shroud will impact the decomposition of the body, either negatively or positively (Table 2.7). There are only 54 cases in the study where the body was covered or wrapped in any type of shroud.

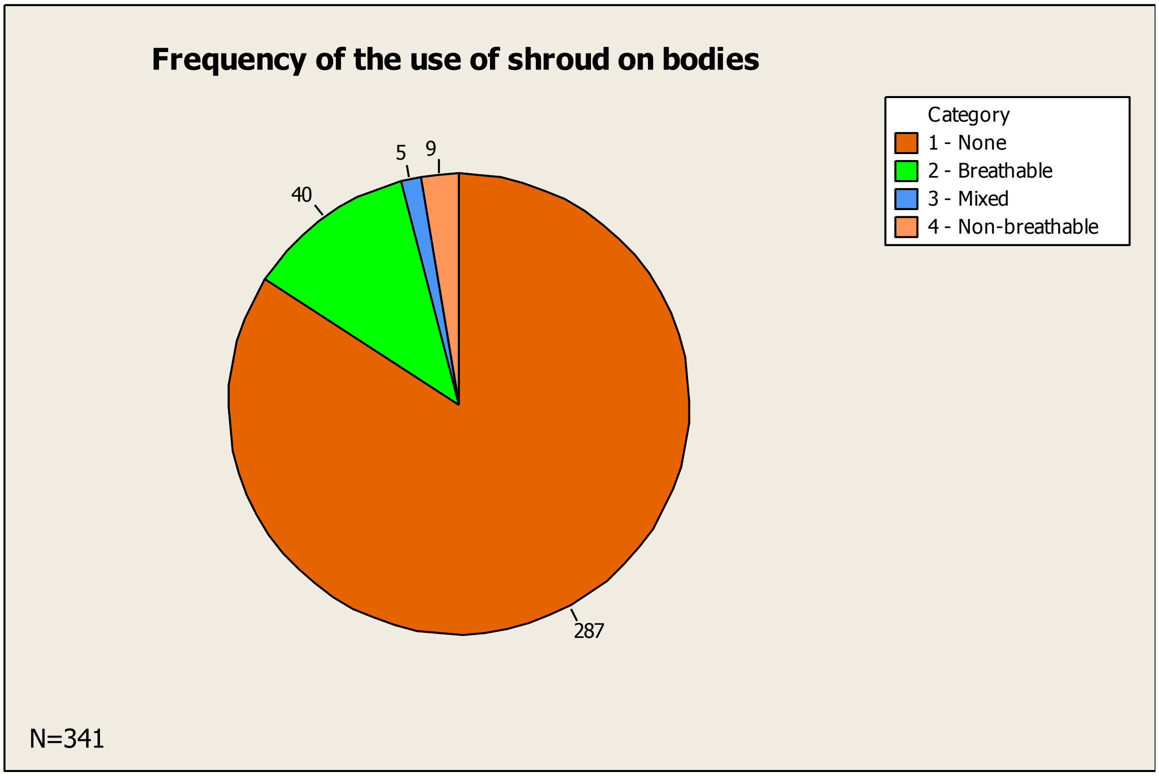


Figure 4.64. The total number of cases with any kind of shroud compared to the cases without. The vast majority of bodies in the study did not have a shroud.

The majority of the cases in the Canadian dataset are without shrouds. There are only 9 cases with non-breathable shrouds (Figure 4.64). The results from the following analysis should be consideration with caution due to the small sample sizes.

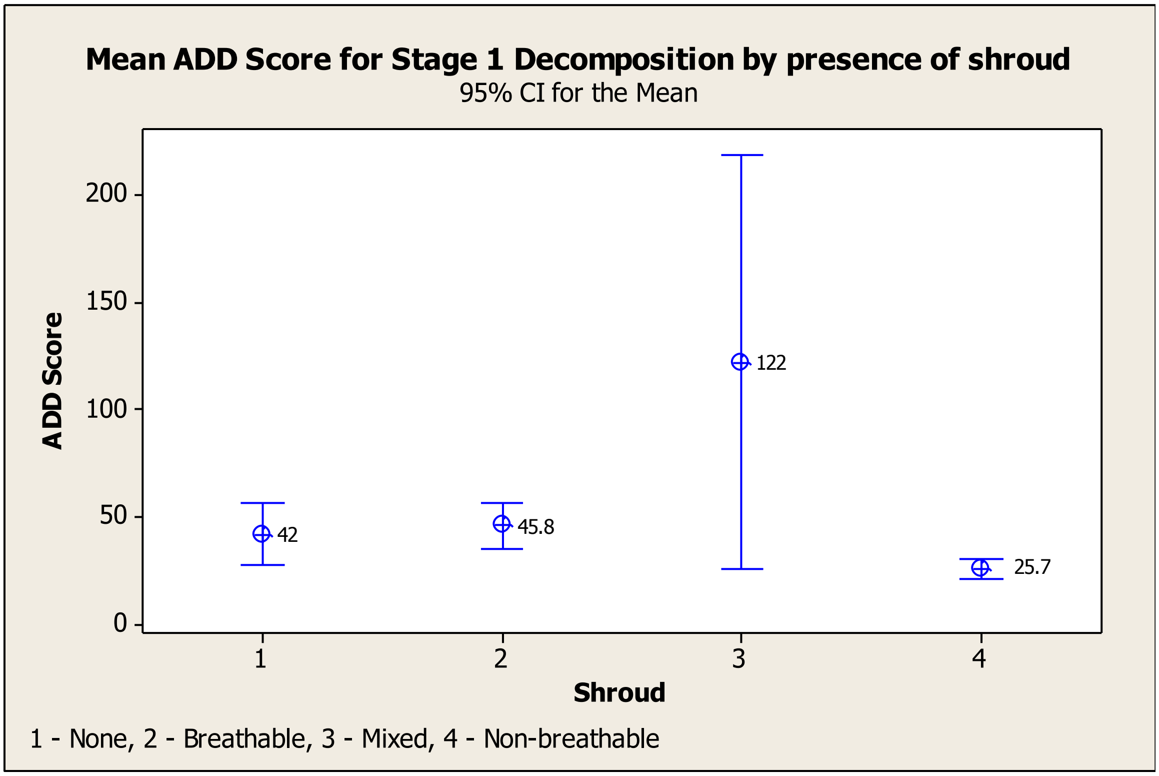


Figure 4.65. ***The comparison of the mean ADD scores for stage 1 decomposition sorted by presence and extent of shroud. The largest group of cases with a shroud is the breathable set with 40 cases. A comparison between group 2 and the group 1 without a shroud shows very little difference in the mean ADD score for stage 1 decomposition. There is a lower ADD score for the group 4 with non-breathable shrouds which suggests a faster rate of decomposition. N=90***

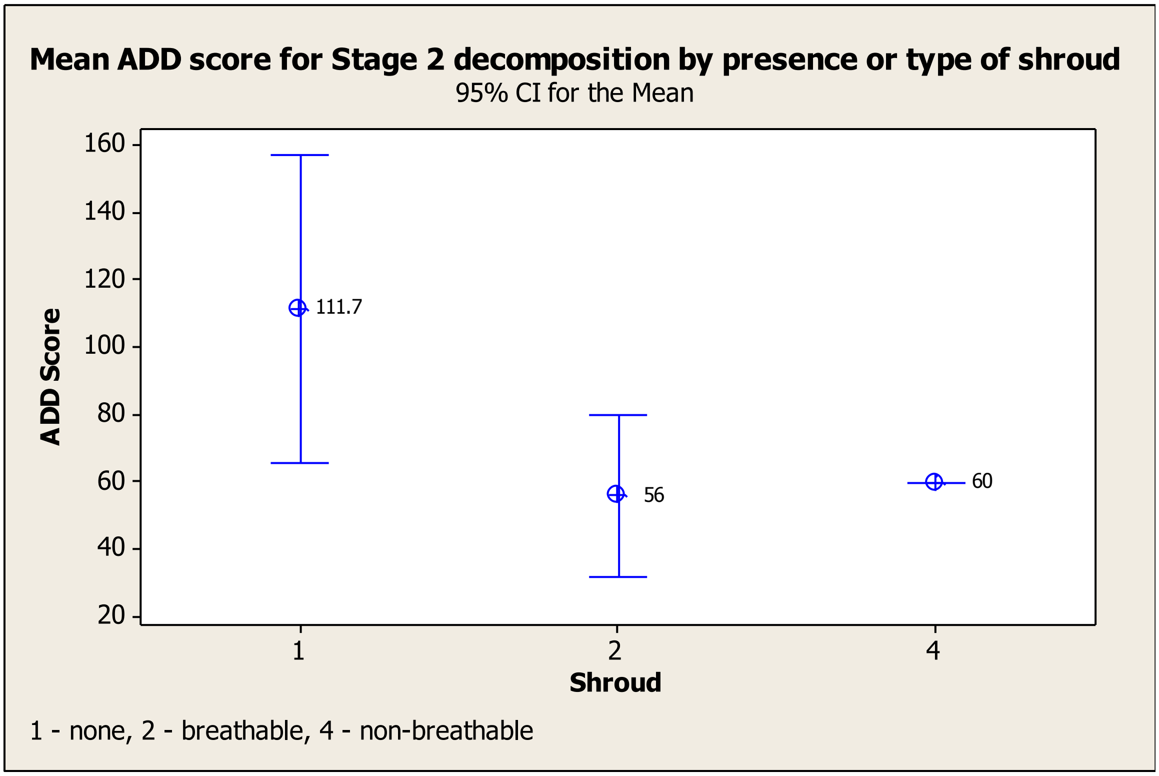


Figure 4.66. The mean ADD scores for the group of bodies without a shroud versus the groups with breathable and non-breathable shrouds for stage 2 decomposition. Group 3 shroud was not represented at this stage. The ADD scores appear to be on average less than for the groups with a shroud compared to the group without. This suggests that decomposition is faster with as opposed to without a shroud.

A comparison was conducted between the cases without shrouds and those with non-breathable shrouds (Figures 4.65 & 4.66). For stage 1 decomposition there does not appear to be a difference between the group with and without a shroud, however the group with a non-breathable shroud does demonstrate a faster rate of decomposition with a lower mean ADD score. For stage 2 decomposition (Figure. 4.66), there is a difference in the mean ADD scores for the groups with and without a shroud. There is a 1.8 ratio decrease in the mean ADD scores for the shroud groups, which again suggests a faster rate of decomposition. The presence of a shroud does appear to make a quantifiable impact on the rate of decomposition in relation to the ADD score, however, due to the small sample sizes, these results should be validated by another study focusing on shrouds as a single independent variable.

The Affect of Sun Exposure to the Progression of Decomposition

The level of sun exposure to a body as it decomposes has been investigated by a number of taphonomy researchers (Table 2.7). The methods used to investigate this variable have generally involved experimentation using animal proxies. Figure 4.67 provides a breakdown of the 96 cases involving bodies decomposing outside on the surface (with a PMI of less than one year). The ratio of cases in shade, partial and full sun is very even with 33%, 30% and 36% respectively. The assessment of sun versus shade was based on the series of photographs taken at the scene over a period of time. There is the potential however that the body may have been in the shade and then exposed to sunlight based on the time of day or season for cases with a long PMI.

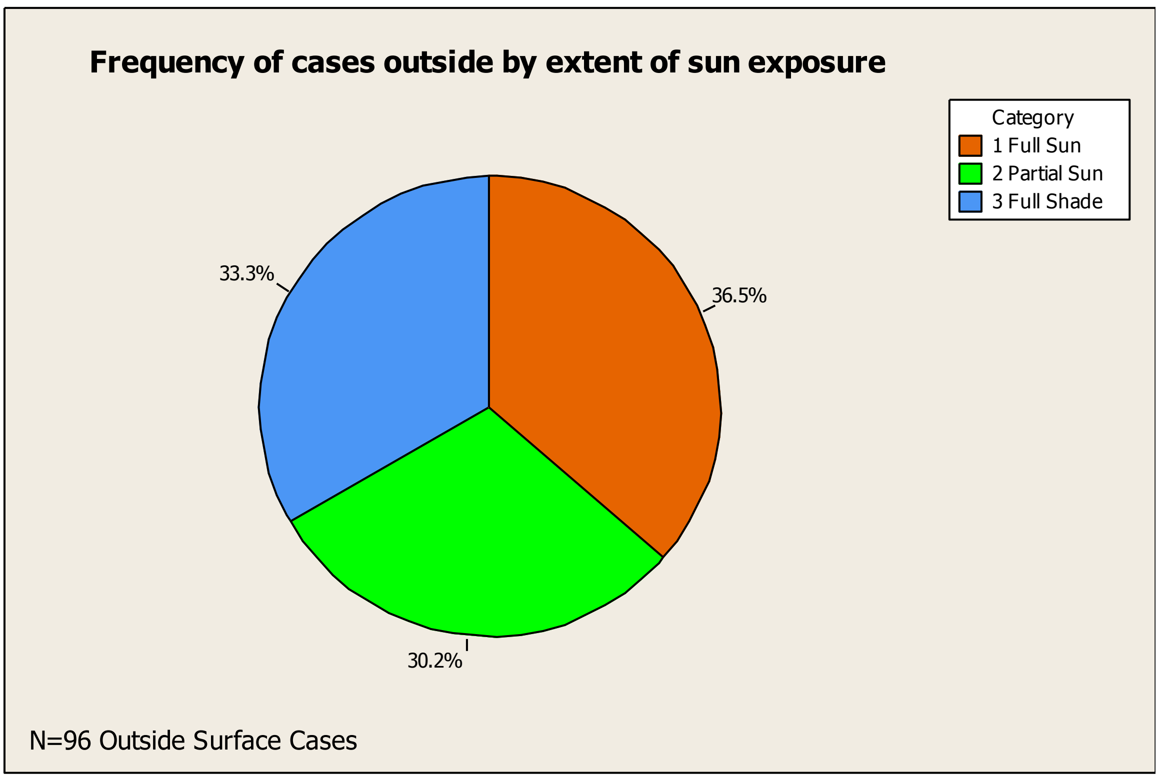


Figure 4.67. The frequency of cases outdoors with bodies in full sun, partial sun and full shade. N=96

There is a fairly even distribution of cases in the outdoor group exposed to the sun, partial and shade. Due to the relatively large sample sizes it is possible to reach some potentially statistically significant conclusions related to the influence of direct sunlight on the decomposition of bodies outdoors.

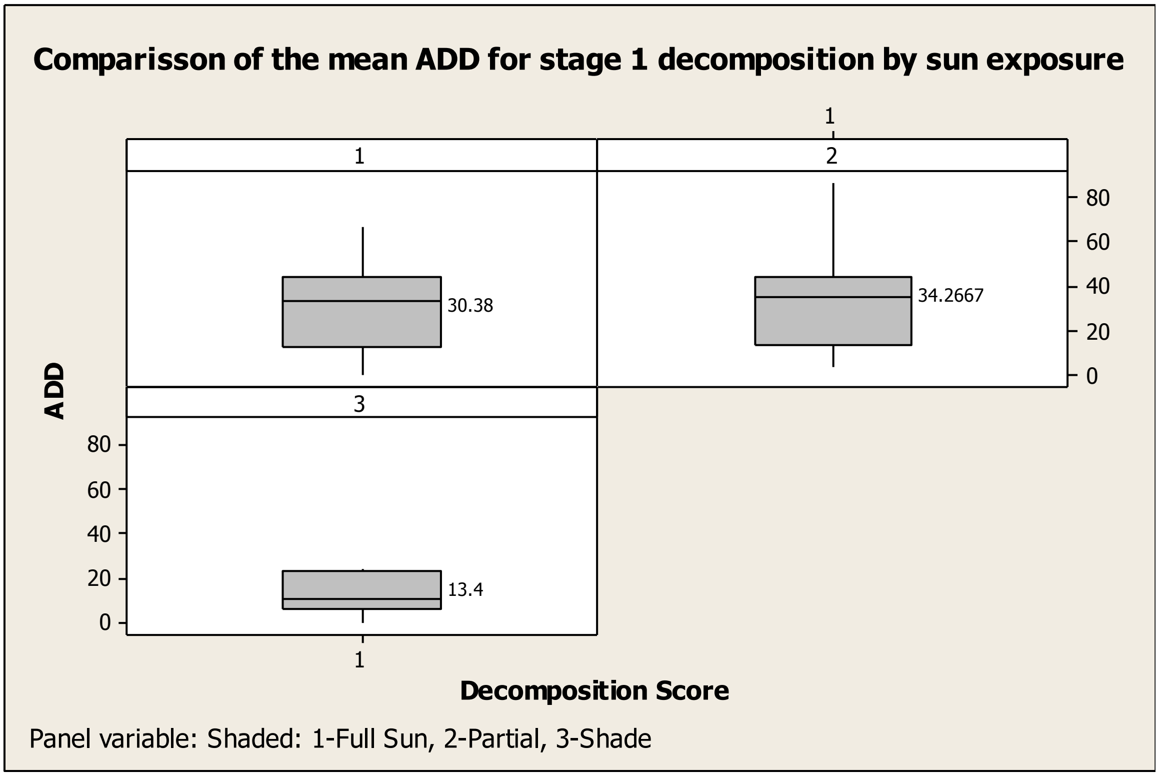


Figure 4.68. ***The comparison of the mean ADD score needed for each group to achieve stage 1 decomposition outdoors. The comparison is between the bodies in full sun (1), partial sun (2) and shade (3). The environment with the fastest (or least amount of temperature), rate of decomposition is the shaded environment. N=96***

Figure 4.68 provides a comparison of the mean ADD score for bodies to achieve stage 1 decomposition in shade, sun and partial shade. The data shows that the fastest rate (lowest mean ADD score) of decomposition is seen with the bodies in full shade. The bodies in partial shade took the longest time, or accumulated temperature to reach stage 1.

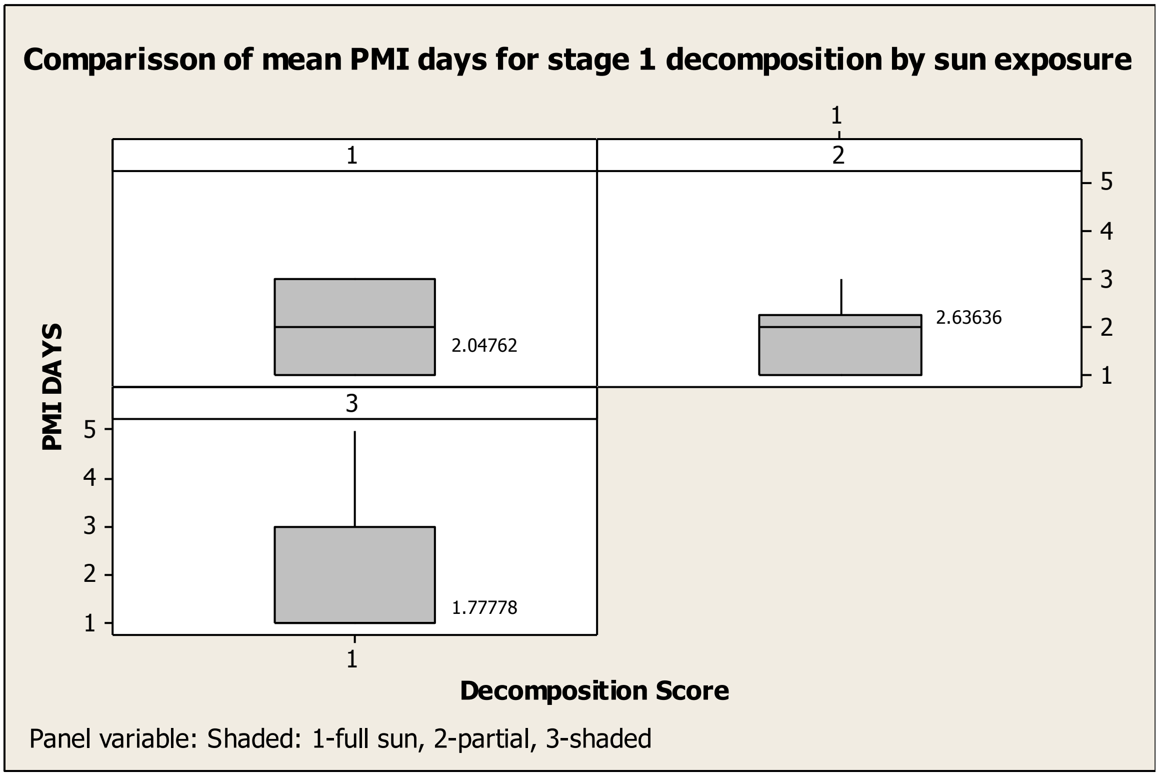


Figure 4.69. ***The comparison of average PMI days to reach stage 1 decomposition outside. Number of cases in each group: 1 N=42, 2 N=22 & 3 N=18 cases. The results suggest that it takes less time to reach stage 1 decomposition in the shaded environment compared to full sun. The longest mean PMI for stage 1 is in the partially shaded environment.***

Figure 4.69 demonstrates that decomposition in full sun is not necessarily faster than bodies decomposing in partial or full shade. It would seem that it takes more time on average for the bodies in partial shade to achieve stage 1 decomposition outside on the surface than in full shade or full sun. The group with the fastest rate of decomposition was the group in full shade.

As the insect involvement by stage of decomposition is sorted into shaded and non-shaded environments it does seem that there is more insect activity in the full sun scenes as opposed to shaded scenes. It is of note that there are bodies in certain stages of decomposition where there is no insect involvement in scenes with all three levels of shade. For example, in the full shade group (Figure 4.69 group 1), there is only one case with insect involvement at stage three decomposition. The other seven cases in this group with insect involvement are with bodies in stages 5 and 6 decomposition.

Relationship of Insect Activity to Extent of Shade

An analysis of the relationship of shade to insect activity was conducted to determine whether or not there was more or less insect activity in the sun versus the shade. Figure 4.70 shows that insect activity is not limited to the shaded environments. There are more cases with insects in full sun (21) compared to those in partial shade (14). The cases with the least amount of insect involvement are the full shade (8).

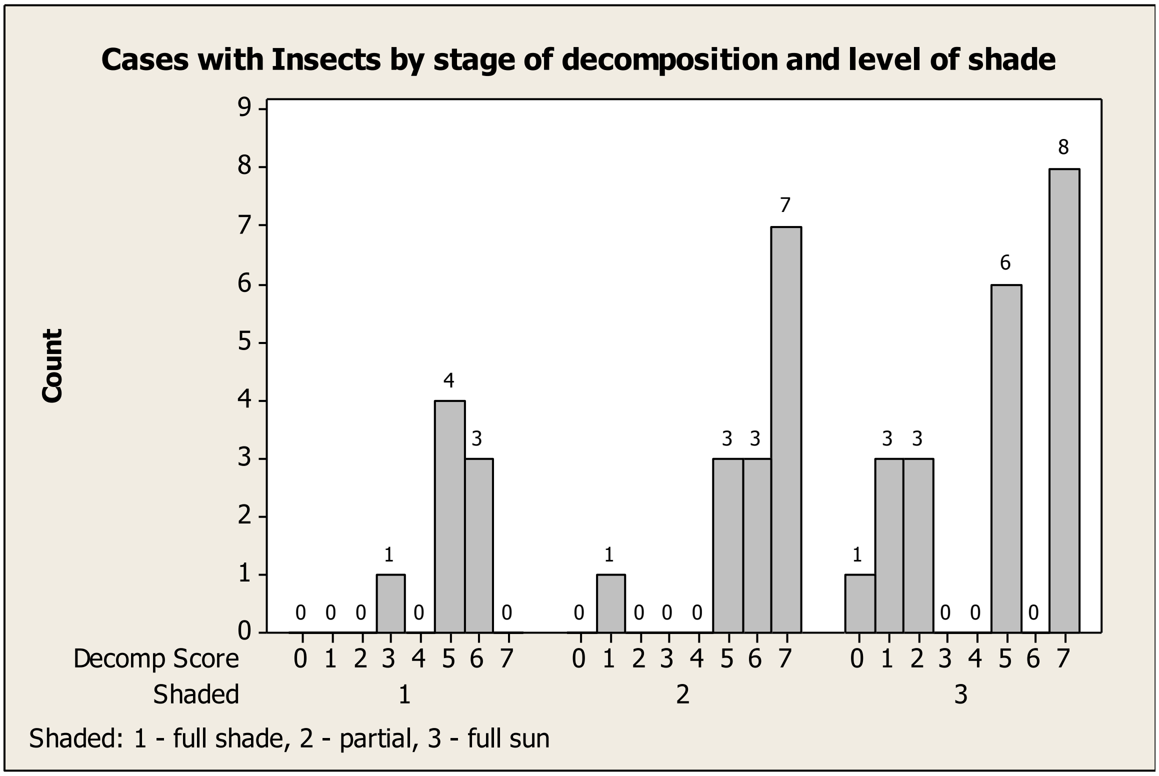


Figure 4.70. The cases with insect involvement by amount of shade. N=43

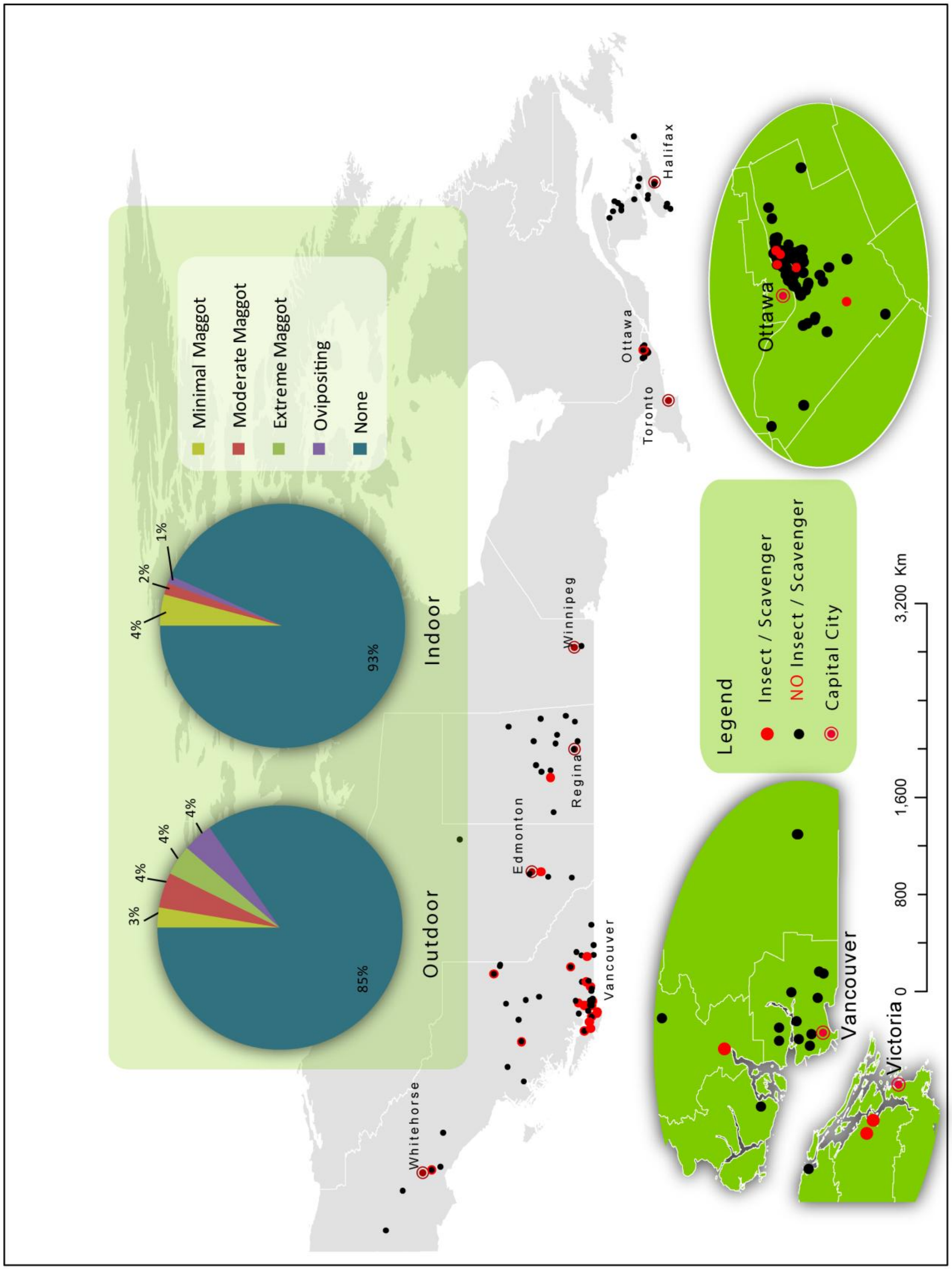
It is interesting to note that insects appear to be involved at different stages of decomposition in different environments. With the shaded and partially shaded cases, involvement appears to occur earlier compared to the sunny environments. With the sunny environment, the insects appear to arrive earlier in the decomposition process.

The Impact of Scavengers and Insects to the Progression of Decomposition

The assessment of the presence or absence of insects at the scene was based on the examination of the crime scene and autopsy photographs as well as any police or autopsy reports. There is a possibility that some insects may have been hidden in or around the body at the scene, however a close inspection of autopsy photographs was made to determine if any insects were present upon exposure of the body at the morgue. Insect involvement includes ovipositing of maggot eggs at one end of the spectrum and a maggot mass engulfing the majority of body at the other end. There is the potential that insects were present on the body at the scene but left sometime prior to the discovery of the body. An assessment of the body at autopsy was conducted to assess any visible impact to tissues as the result of insect involvement.

Only 10% of the total cases in this study demonstrated any visible sign of insect involvement. Only 15% of cases outdoors had any visible sign of insect involvement and 7% for indoor scene, regardless of geographic location or season across Canada (Figure 4.71). All of the cases have been mapped across Canada in Figure 4.71. Although there does appear to be a higher concentration of cases without insect or scavenger involvement in the prairies and east coast, compared to the west coast of Canada, it is more beneficial to examined seasonal presence of insects across Canada.

Figure 4.71. ***Distribution of cases with and without insects and scavenging***



The Visible Presence and Extent of Insects on Bodies Outside

The overall number of cases without insect involvement outdoor and indoor was an unexpected result of this study. The assumption of forensic entomology is that, given appropriate access to the body, insects will colonize a body soon after death. Figure 4.72 demonstrates however, that the majority of bodies decomposing on the surface outside are discovered without any visible signs of insect involvement.

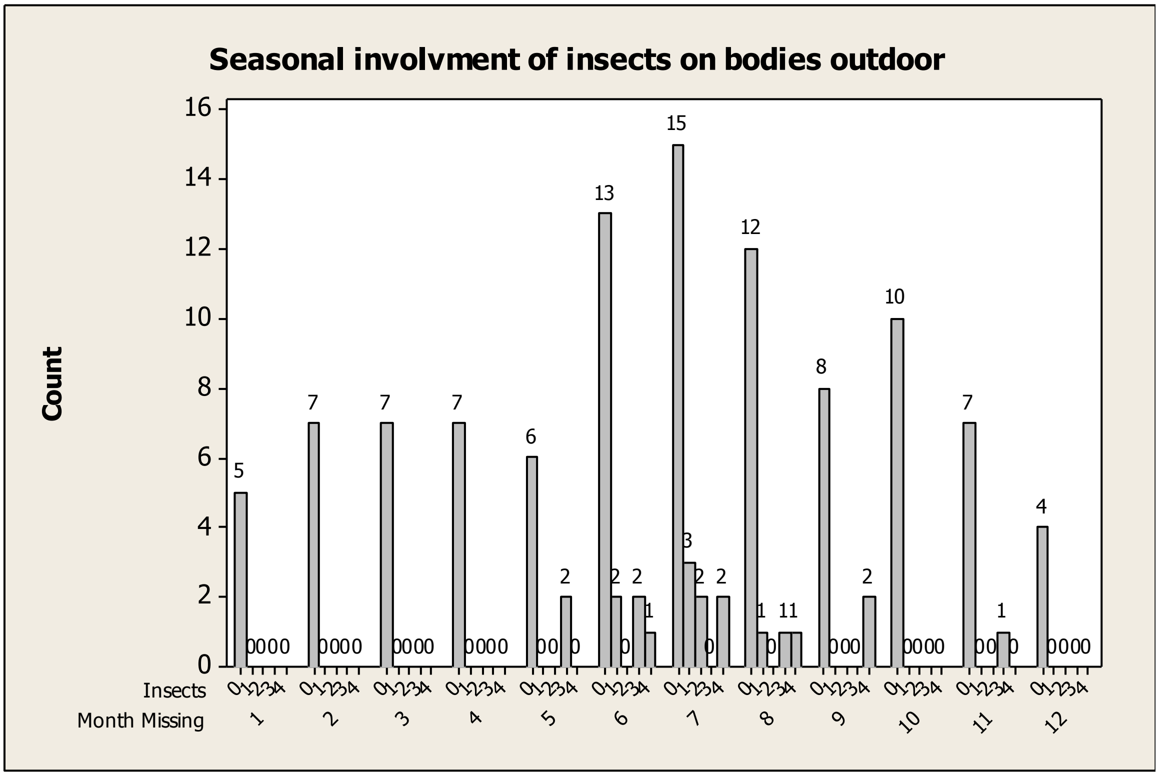


Figure 4.72. The distribution of cases with and without insect involvement by the month of the year. The levels of insect involvement are from 0 which is no visible involvement, 1-ovipositing, 2-minimal insect activity, 3-moderate insect activity and 4-extreme insect activity. There are many more cases in summer where the is no indication of the presence of insects versus those cases with insects. PMI of less than 1 year (121 cases)

An explanation for the absence of insects at a scene outdoor may be the season, as there minimal to no insects present during the Canadian winter months. Figure 4.72 demonstrated that the majority of insect activity occurring on bodies outside does occur during the summer months of June through August, however, there are many more cases during the summer months which do not have any visible sign of insect involvement.

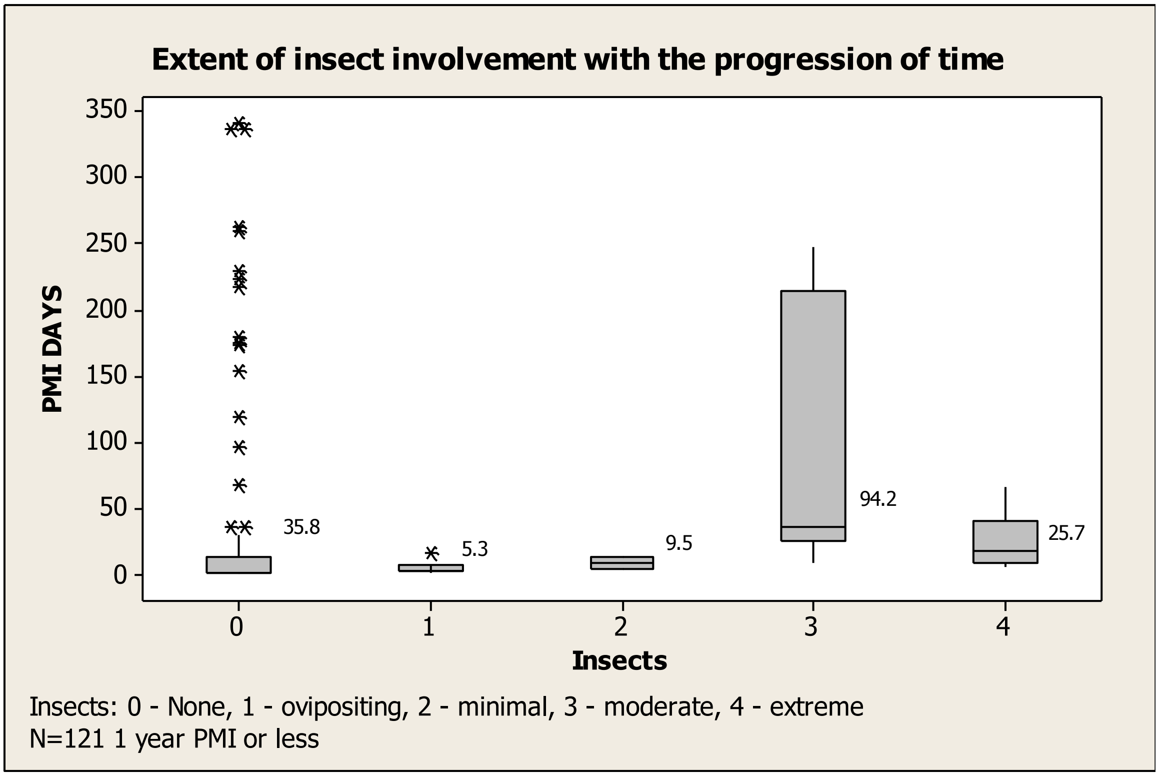


Figure 4.73. The mean PMI in days for the progression of insect involvement for bodies outdoors. Group 0 is the cases where there are no visible insects. The "*" represent a specific cases outside the mean box plot calculation. These bodies can be located with a PMI of up to 1 year. There is considerable variability in the time it takes for the moderate to extreme levels of insect involvement.

Figure 4.73 provides the mean PMI in days for the bodies with and without insect involvement. As the retrospective study can only evaluate the body at the time of discovery, it is not possible to comment on the time of arrival of insects. These results reflect the mean PMI in days for the presence, absence or extent of insects on bodies evaluated from the day of their discovery.

These results suggest that a body can be exposed outside for a mean duration of 5 days without visible insect colonization, regardless of season. An average time period required for the involvement of a minimum amount of insects is between 9 to 10 days. The time ranges for the appearance of medium to large maggot masses is extremely variable. Bodies can be found without visible insects for the full spectrum of the post mortem interval.

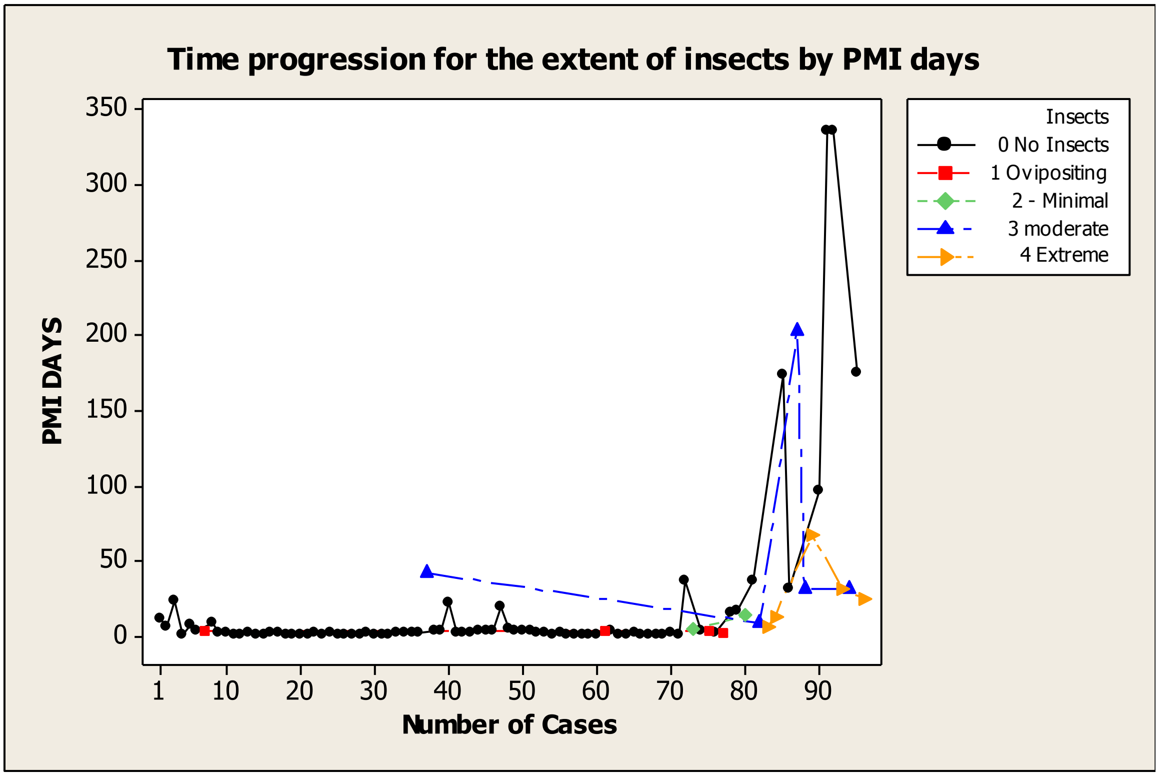


Figure 4.74. The PMI for each case with (1 – 4) and without (0) insect involvement. The cases without insects can occur within the full range of PMI days. There is considerable variability in the time it takes for each level or extent of insects to occur on the body in cases outdoor. N=96

Figure 4.74 is a time series plot for the presence and stage of insect involvement in the outdoor cases. Cases with a lack of insects can be seen at any time in the series (Group 0- black). The moderate involvement of insects can be seen from 0 to 200 days PMI. The extreme involvement of insects has a tighter time range at the end of the time scale up to 55 days PMI.

This study suggests that the majority of bodies recovered from an outside environment during any month of the year in Canada will not necessarily have insect involvement. It is unknown why some bodies will colonized by insects and others will not.

Insects Indoors

Only 7% of all of the indoor cases in Canada had any sign of visible insect involvement (Figure 4.75). During the summer months it is assumed that insects will colonize the body if there is appropriate access. The frequency of insect involvement indoors is less than the frequency found outside, presumably due to access issues. There is however only an 8% difference in the frequency between inside and outside scene types.

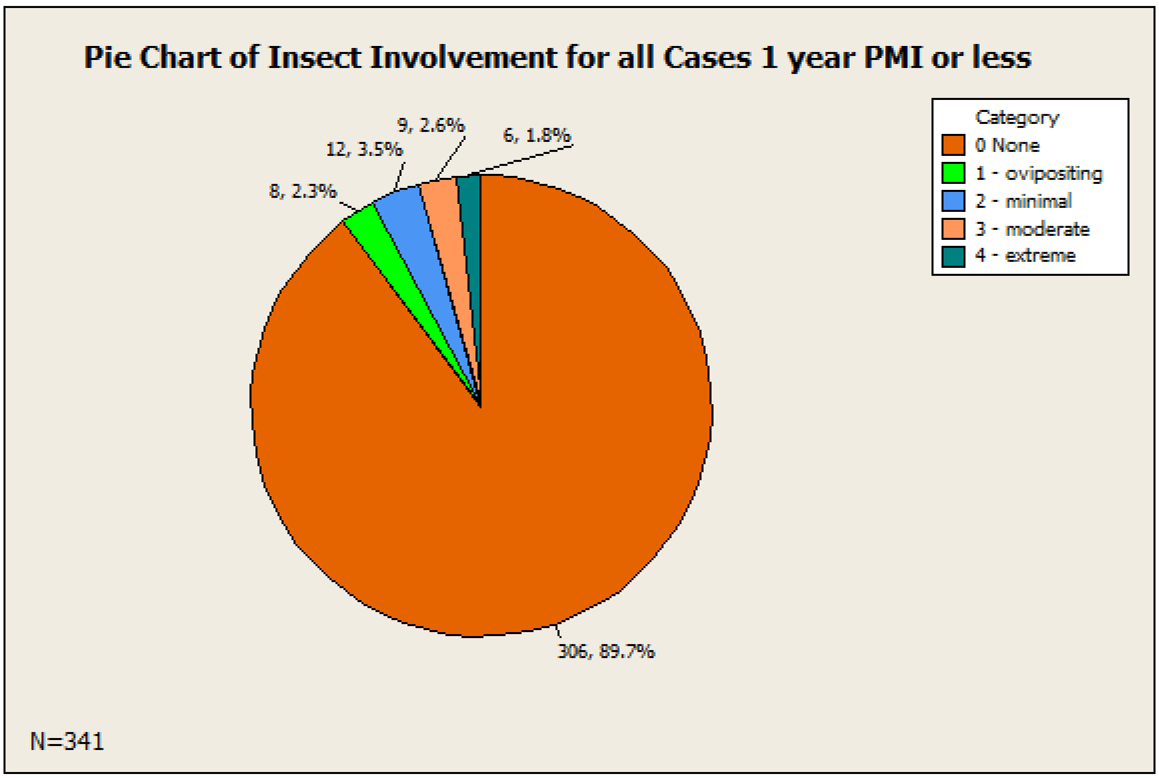


Figure 4.75. ***The frequency insect involvement for all cases in the dataset with 1 year PMI or less. Almost 90% of all cases in all four types of scenes have no visible indication of insect involvement.***

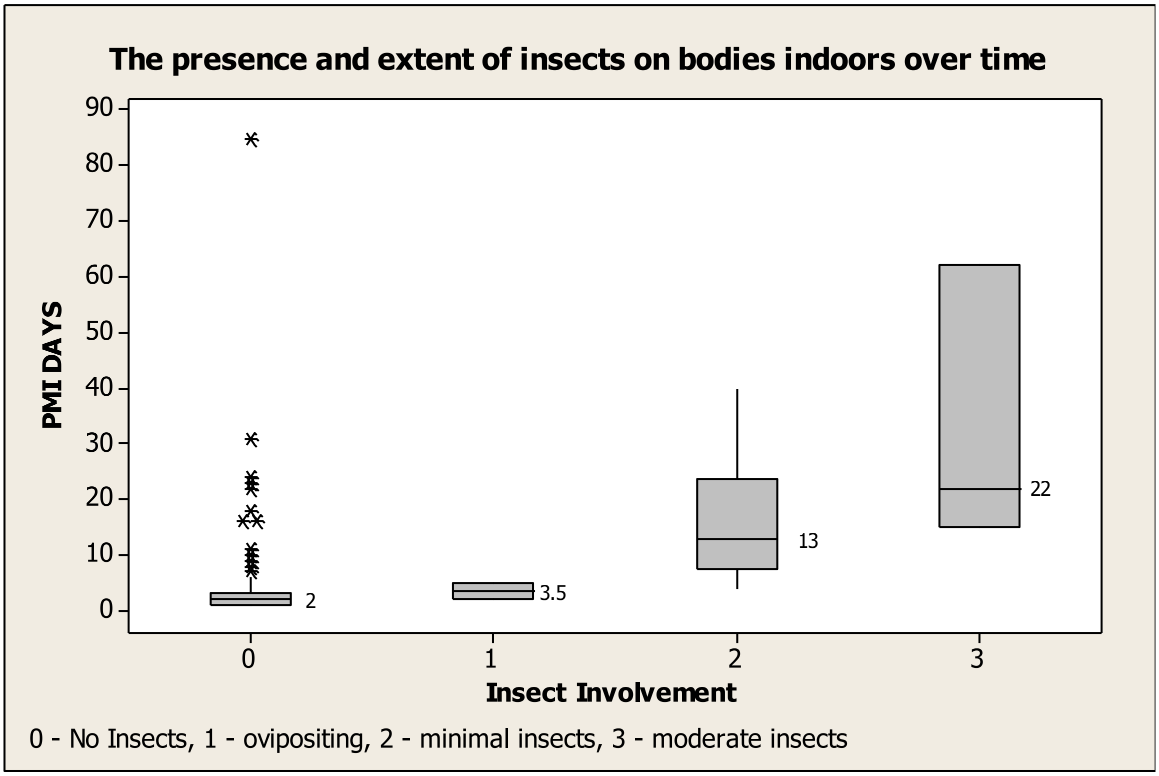


Figure 4.76. ***The mean PMI days for the extent of insects indoors. There were no cases of extreme insect involvement indoors. The '0' group represents those cases where there were no visible signs of any insect involvement. There was no relationship of time to the increasing involvement of insects. The error rate for the mean PMI days increased with insect involvement. There are cases "*" which have been located after a range of 30 or more days with no visible insect involvement. N= 193.***

The seasonality for insects indoors is similar to that of the outdoor cases. Figure 4.76 shows the average PMI in days for the presence of ovipositing (1), minimal (2) and moderate (2) insect involvement for indoor cases. The full range of time is represented for the cases with no insect involvement (0). The asteryxes in the box plot for the group of cases without insects (0) show cases without visible insect involvement from 0 to a maximum of 85 days PMI.

Time does appear to be a predictive variable for the increasing involvement of insects indoors. Ovipositing is seen with bodies which have a mean PMI of 3.5 days. Minimal insect involvement is noted on average at 13 days and moderate insect involvement at 22 days PMI. There are no cases in this dataset inside with extreme insect involvement.

Scavenging

Scavenging in this study includes impacts to the body by small and large mammals, rodents, avian scavengers as well as marine scavengers such as crab or other sea life. The involvement of scavengers was based on tissue damage to the body assessed on the day of discovery at the scene or at the morgue.

Scavenging of the Bodies in Water

There are five cases from the water environment (Figure 4.77) that demonstrate any evidence of marine scavenging which may include insect involvement. Of these five cases, the scavenging appears to have occurred prior to or during putrefaction and at the onset of skeletonization. This is a small dataset; however it does suggest that scavengers do impact the body in water even towards the end of the decompositional sequence in Canada.

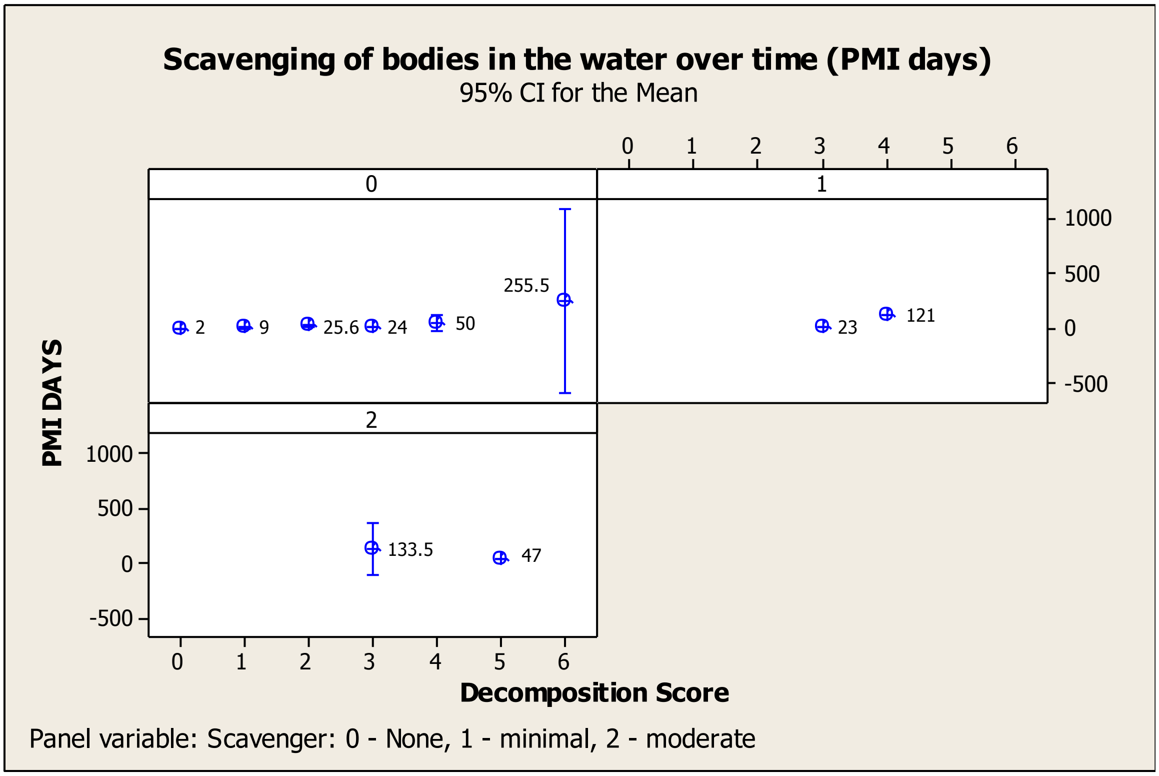


Figure 4.77. These three charts show the mean PMI days for bodies with or without evidence of scavenging in the water. Group '0' is the cases without scavenging and provides the mean PMI days for the cases found at a specific stage of decomposition. Group '1' has two cases with minimal scavenging at 23 days for stage 3 decomposition and 121 days for stage 4 decomposition. There are three cases with moderate scavenging. The mean PMI days for moderate scavenging at stage 3 decomposition is 133.5 days and 47 days for the case at stage 5 decomposition.

There does not appear to be any predictability in the time it takes or the extent of scavenging for bodies in water environment. Scavenging appears to be opportunistic and unpredictable in nature. It is important to consider the small sample size of this dataset with only 27 cases.

Scavenging of the Bodies Outside on the Surface

There are 13 cases discovered outside with visible signs of tissue damage due to scavenging (Fig. 4.78). This represents only 13% of all cases outdoors. The majority of bodies exposed on the surface outdoors during any month of the year have not been visibly impacted by scavengers.

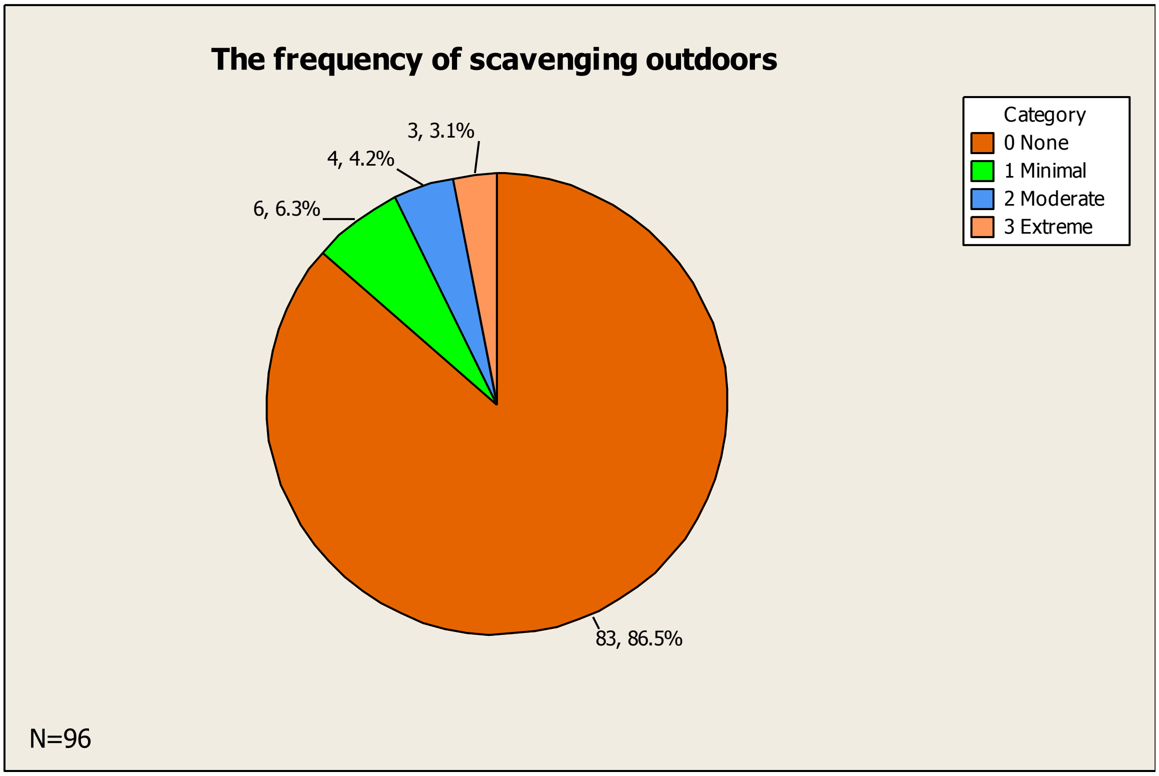


Figure 4.78. The frequency of cases in the outdoor surface data set with any visible signs of scavenging. Only 13% of all the outdoor cases have any visible sign of animal/avian scavenging

Scavenging involves a consumption of the tissue and it has been proposed that this tissue removal will either positively or negatively impact the rate of baseline decomposition by interfering with the natural processes of putrefaction. Figure 3-79 provides the average PMI days for each extent of scavenging from none (0) to minimal (1), moderate (2) and extreme (3). The extent is gauged by the amount of tissue consumed by scavengers. Moderate would be less than 50% and extreme more than 50%.

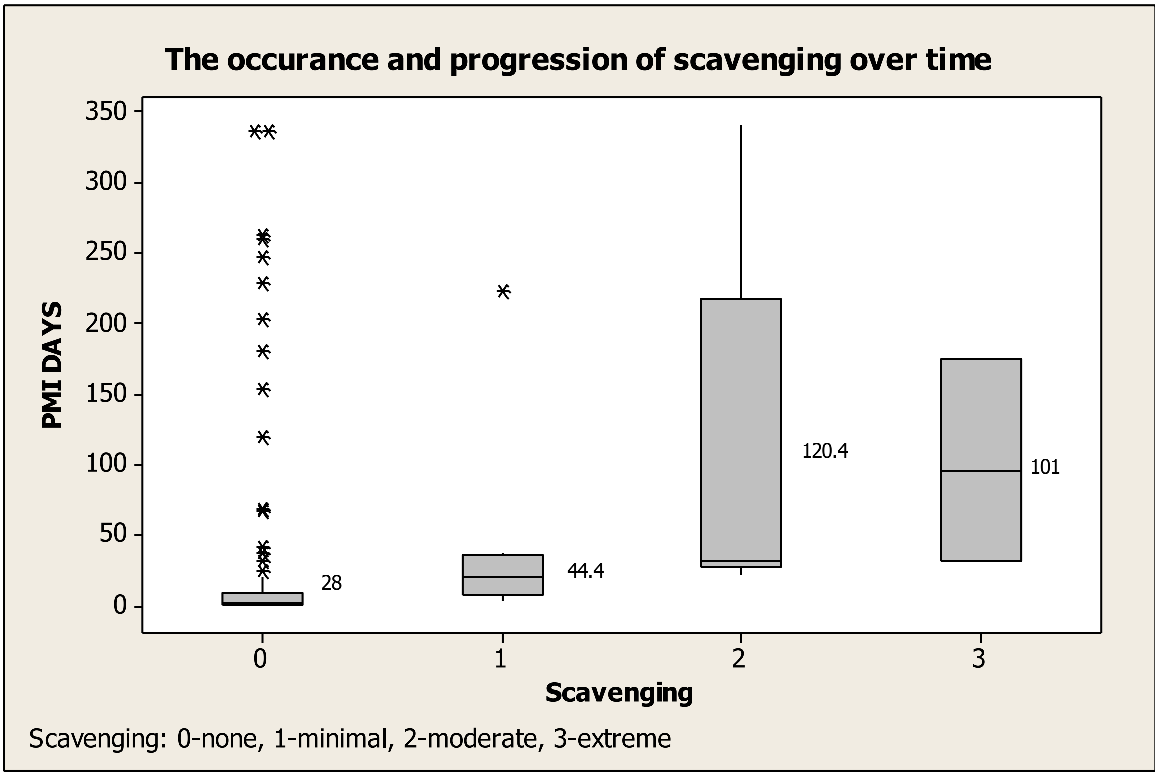


Figure 4.79. The mean PMI days for the extent of scavenging from minimal to extreme. The cases with no visible scavenging is the "0" group. Bodies without any sign of scavenging have been found outside up to 1 year PMI. There is no correlation of the extent of scavenging with time.

The average PMI days for bodies without scavenging is approximately 28 days, however, bodies without scavenging can be found on the surface outside from 0 to 340 days PMI. There is considerable variability in the extent of scavenging based on time with a large overlap between all the groups. The average time it takes for a minimal amount in Canada is 44 days. Moderate scavenging is seen at 120 days with a large error rate. On average extreme scavenging can be seen at 101 days, again with a large error rate. Time therefore cannot be considered a predictor variable for the onset or extent of scavenging outside in Canada.

Many crime scene and death investigators in Canada make the assumption that scavenging occurs most frequently in winter time due to competition and scarcity of food supplies. Spring is also another time period of food competition with many species giving birth to offspring and the emergence of hibernation for species such as bear.

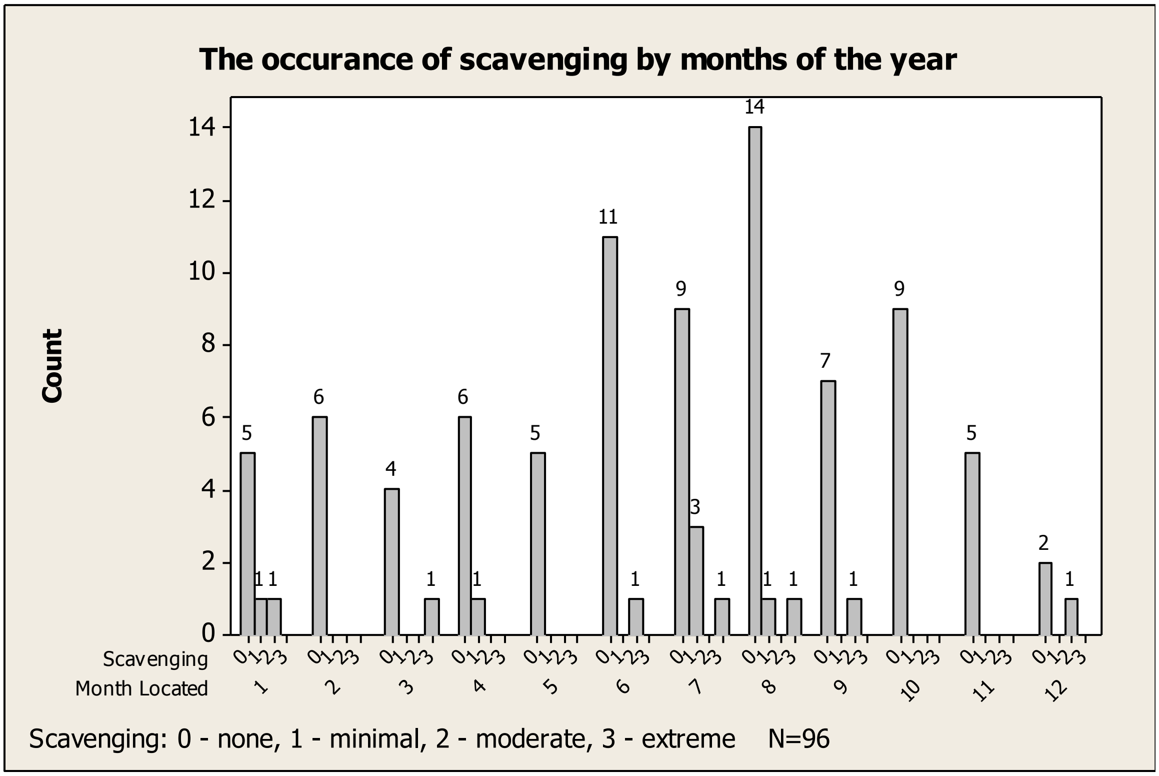


Figure 4.80. The numbers of cases with and without scavenging by each month of the year. The cases have been associated to the month that the bodies were found in. There does not appear to be season pattern for scavenging outdoors in Canada.

Figure 4.80 does not support the assumption that the majority of scavenging occurs during the wintertime. According to these results, the majority of scavenging occurs during the summer months from May to September. There are only three cases with minimal scavenging between October and March. The chart shows the months when the bodies were found. These bodies could have been scavenged during any time in the post mortem interval. It would seem that the number of cases with scavenging is more proportional to the availability of bodies rather that the seasonality of scavengers.

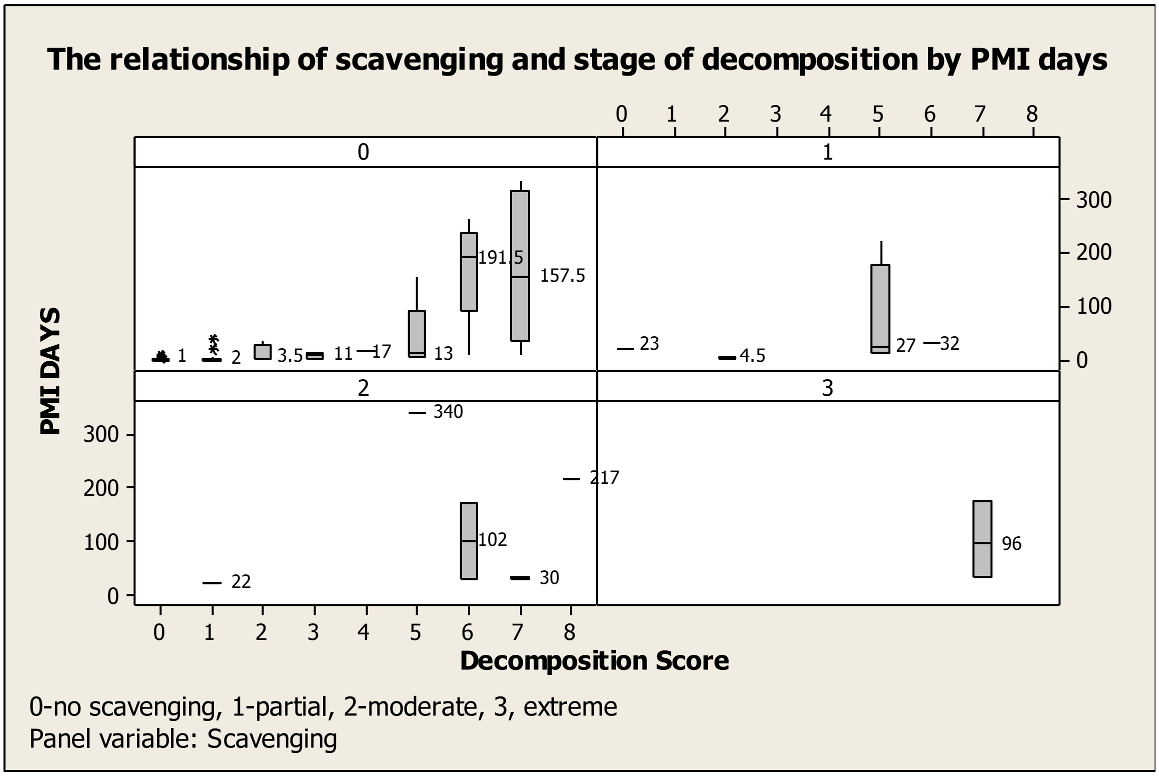


Figure 4.81. ***The mean PMI days for each level of scavenging by stage of decomposition. Group 1 – 3 provides the mean PMI days for the stage of decomposition for that extent of scavenging: No scavenging (0), partial (1), moderate (2) and (3) extreme. There does not appear to be a correlation between the stage of decomposition and the extent or incidence of scavenging.***

Another prevailing assumption with crime scene investigators is that there will be limited scavenging after a certain stage in the progression of decomposition. Figure 4.81 demonstrates that there does not appear to be an association of scavenging to a specific range of decompositional stages. Scavenging in this study occurred as early as four days for the second stage of decomposition with partial scavenging as late as 340 days at the fifth stage of decomposition. A body was moderately skeletonized at 28 days with full skeletonization taking as long as 217 days. There does not appear to be a steady progression of scavenging over time, nor is scavenging related to a particular stage of decomposition. It is unknown when the scavenging has occurred but it was documented on bodies ranging from no visible decomposition to fully skeletonized.

The extent of insect and scavenger impact appears to be relatively low in the Canadian dataset. The impact of scavenging to the overall rate of decomposition will be evaluated in combination with the environmental variables in order to assess its contribution.

Outdoor Model for the immediate context and Environmental Variables

An evaluation of the environmental and immediate context variables for bodies outdoor on the surface was conducted to determine which variables or complex of variables had an impact, either positive or negative on the progression of decomposition. For the multivariate analysis of the variables for each scene type, an evaluation was conducted of the variable correlations using a correlation matrix. The only two variables which demonstrated a high degree of correlation was PMI and ADD score. To avoid multicolinearity, these two variables were not put into the model together. All other variables demonstrated low levels of correlation.

Table 4.21. Regression analysis of environmental and immediate context variables

Regression Analysis: Decomposition Score versus Total Precipitation, ADD, Shaded, Clothing, Shroud, Scavenging and Insects.				
The regression equation is				
Decomp Score = 0.457 + 0.00279 Total Precipitation + 0.000841 ADD acc temp				
- 0.075 Shaded + 0.132 Clothing - 0.114 Shroud + 1.35 Scavenging				
+ 1.05 Insects				
Predictor	Coef	SE Coef	T	P
Constant	0.4575	0.5060	0.90	0.368
Total Precipitation	0.002793	0.001560	1.79	0.077
ADD Score	0.0008413	0.0006201	1.36	0.178
Shaded	-0.0746	0.1350	-0.55	0.582
Clothing	0.13234	0.09282	1.43	0.157
Shroud	-0.1136	0.1929	-0.59	0.557
Scavenging	1.3548	0.1829	7.41	0.000
Insects	1.0457	0.1021	10.24	0.000
S = 1.02074 R^2 = 80.7% R^2(adj) = 79.2%				

The regression analysis shown in Table 4.21 above is an analysis of both environmental variables such as precipitation and temperature and immediate context variables which include sun exposure, extent and presence of clothing and shrouds, insects and scavenging. As can be seen by the P-values, only scavenging and insects have significant impact on the stage of decomposition. All these variables in combination however explain 79.2% of the variability in the stage of decomposition. The extent of shade and shrouds has a negative impact on the progression of decomposition, compared to the other variables which have a positive impact. This means that the greater the extent of clothing or presence of un-breathable shrouds, the slower the rate of decomposition. In an attempt to rank the relative value of these variables a stepwise regression analysis was conducted with these same variables with the cases exposed on the surface outside.

Table 4.22 provides the results of the stepwise regression analysis. The only variable that was removed was the shroud variable. The maximum R^2 (adj) is 79.5%. If we take a look at the Mallows Cp values for the six remaining variables, the smaller the value the better it is as this reflects the amount of error in the model. The model with all five variables has at small standard error of regression (1.01) and a low Mallows Cp. Value (4.6) with the highest R^2(adj) value of 79.5%.

Table 4.22. Stepwise Regression analysis of Environmental and Immediate Context Variables: Decomposition Score versus Total Precipitation, ADD, Shaded, Clothing, Shroud, Scavenging & Insects

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Decomp Score on 7 predictors, with N = 96

Step	1	2	3	4	5	6
Constant	1.14253	0.78479	0.61191	0.60443	0.13793	0.09641
Insects	1.240	1.091	0.972	1.016	1.032	1.074
T-Value	7.59	9.00	9.99	10.12	10.33	11.21
P-Value	0.000	0.000	0.000	0.000	0.000	0.000
ADD acc temp		0.00227	0.00190	0.00099	0.00086	
T-Value		8.98	9.22	1.60	1.40	
P-Value		0.000	0.000	0.113	0.164	
Scavenging			1.23	1.36	1.34	1.46
T-Value			7.52	7.51	7.47	9.19
P-Value			0.000	0.000	0.000	0.000
Total Precipitation				0.00245	0.00267	0.00472
T-Value				1.58	1.74	9.17
P-Value				0.118	0.086	0.000
Clothing					0.149	0.164
T-Value					1.67	1.84
P-Value					0.098	0.069
S	1.77	1.30	1.03	1.02	1.01	1.02
R^2	38.01	66.81	79.46	80.00	80.61	80.18
R^2(adj)	**37.35**	**66.10**	**78.79**	**79.13**	**79.53**	**79.31**
Mallows Cp	191.3	61.7	5.9	5.4	4.6	4.6

There are fewer environmental and immediate context variables with bodies located indoors. The variables examined for these scene types included, the temperature (ADD), extent of clothing, shroud and impact of insects (Table 4.23).

Table 4.23. Stepwise regression for environmental and immediate context variables for indoor scenes

Stepwise Regression: decomposition score versus ADD Score, Clothing, Insects and Shroud			
Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15			
Response is decomposition score on 4 predictors, with N = 191			
Step	1	2	3
Constant	0.9297	0.9151	0.6542
ADD acc temp	0.00489	0.00343	0.00346
T-Value	10.59	7.10	7.19
P-Value	0.000	0.000	0.000
Insects	1.00	1.00	
T-Value	6.25	6.26	
P-Value	0.000	0.000	
Shroud		0.21	
T-Value		1.54	
P-Value		0.124	
S	1.15	1.05	1.05
R^2	37.25	48.05	48.71
R^2(adj)	36.91	47.50	47.88
Mallows Cp	42.0	4.6	4.2

Of the four variables examined for indoor scene types, stepwise regression removed clothing from the model as it fell below the significance threshold. Only two of the variables were found to be significant; temperature and insects, both with P-values of 0.000 which is highly significant. The R^2(adj) result for the combination of all three variables in this model is only 47.8%. This means that less than half the variability in the decomposition score for indoor scenes can be correlated to changes in temperature, insects or shrouds.

The stepwise regression for environmental and immediate context variables for water scenes included temperature, level of submersion, clothing, shroud and extent of scavengers and insects.

Table 4.24. Stepwise Regression for Environmental and Immediate Context Variables in Water Scenes

Stepwise Regression: Decomposition versus ADD Score, Submersion, Clothing, Shroud, Scavenger & Insects		
Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15		
Response is Decomposition Score on 6 predictors, with N = 27		
Step	1	2
Constant	2.053	3.554
ADD acc temp	0.00130	0.00130
T-Value	3.63	3.97
P-Value	0.001	0.001
Submersion		-0.68
T-Value		-2.37
P-Value		0.026
S	1.41	1.30
R^2	34.54	46.93
R^2(adj)	31.92	42.51
Mallows Cp	2.8	-0.1

Table 4.24 provides the results of the stepwise regression for the water scenes. Only two out of six variables were determined to have any significance. Temperature was found to have a P-value of 0.001 which is highly significant and level of submersion had a negative impact on the stage of decomposition. The more submerged the body, the more it retarded the progression of decomposition. The submersion variable had a P-value of 0.026 which is significant. All other variables were removed from the model, including insects, scavengers, clothing and shrouds. Clothing and shrouds do not have an influence on the relative rate of decomposition in water cases. These results should be evaluated with the caution due to the small sample size. The R^2(adj) for the model

including temperature and level of submersion is only 42.5% which means that these two variables account for only a small amount of the variability in the stage of decomposition in water scenes.

When the temperature variable is replaced by time, or PMI days, the R^2(adj) results improves to 53.8% with a Mallows cp of 3.0 and standards error of regression (S) of 1.16. In relation to this small sample of water cases in Canada, time is a more useful variable to use as opposed to temperature when it comes to the predictability of the stage of decomposition in water scenes.

Intrinsic Variables

Intrinsic variables are those variables which are specific to that individual or the conditions their death. These variables include: age, sex, body size, manner of death, type and extent of trauma and blood loss. The presence and extent of drugs and alcohol ingested by the victim around the time of their death is also considered to be an intrinsic variable.

The Impact of Age to the Progression of Decomposition

The ages of the individuals in this study range from fetal, to 97 years (Figure 4.82). The majority of the cases however are adults between the ages of 20 and 50. The average age of all cases is approximately 40 years old and there is a range of ages for each stage of decomposition. Individuals in the study with an age of less than one year were assigned a score of zero. There are 7 of these cases with a zero age score in this dataset.

Figure 4.83 is a histogram of the average ADD score needed for each age group to reach stage 1 decomposition regardless of scene type in the dataset. For the purposes of this analysis, the ages have been divided into sets which represent the biological stages of life as well as ten year age groups. There is a visible increase in mean ADD scores from young to old. The smaller the mean ADD score, the less mean temperature needed to achieve that stage of decomposition on average. This differential in the rate of decomposition is demonstrated in a chart in Figure 4.104 near the end of the section. The smaller mean ADD scores in the younger versus older groups would suggest that decomposition is relatively faster in younger individuals compared to the older individuals. As an adult there is little variability in the time it takes to reach stage 1.

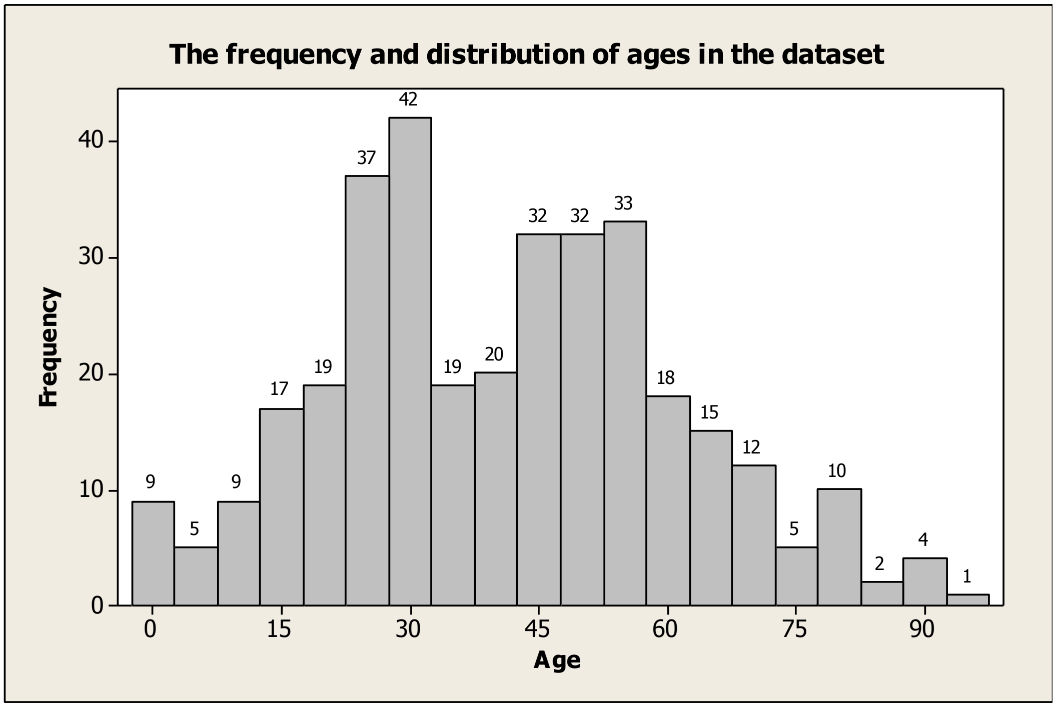


Figure 4.82. ***The frequency of ages in 5 year sets for the dataset. The cases with a score of "0" represent babies before the age of 1 year. N=341.***

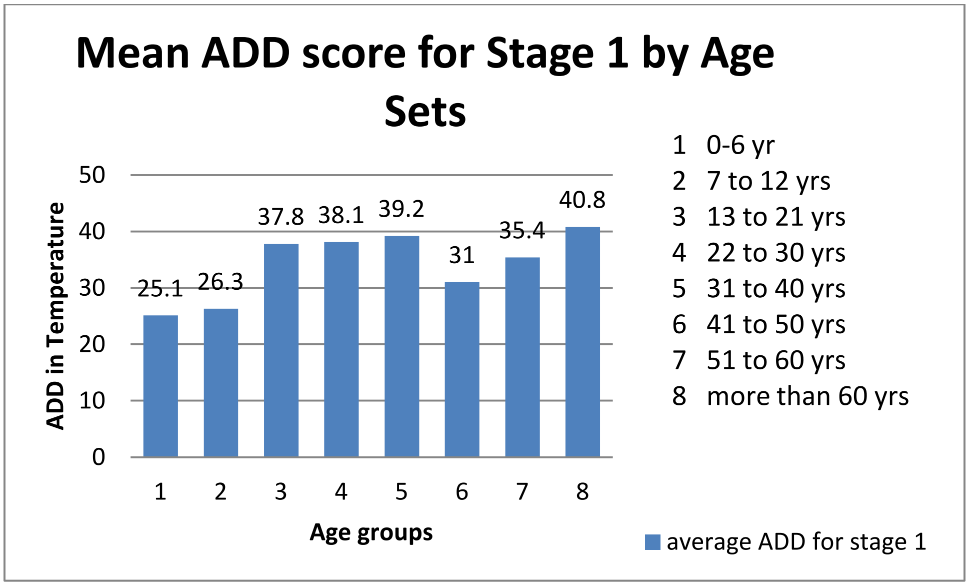


Figure 4.83. The mean ADD score for each age set to achieve stage one decomposition. A total of 90 cases from newborn to 90 years were used for this calculation. There does appear to be lower mean ADD scores for the younger groups between the ages of 0 and 12 years old compared to the adults. The lower the mean ADD score the faster the rate of decomposition.

The evaluation of mean ADD for each age group to reach stage 1 decomposition does elucidate a general pattern of relatively faster decomposition from young to old; however a regression analysis of age as an independent variable and stage of decomposition did not result in age having any value in predicting the stage of decomposition.

There are biological changes which occur to our bodies as we mature and age, these changes are generally related to hormonal or body fat /mass distribution but may also relate to the complexity and frequency of bacteria as our gut flora matures over time. The complexity and frequency of gut flora can be affected by disease and use of antibiotics over time. It may be more useful to divide the cases into age sets which may be more reflective of our biological changes. The following section examines the differences between babies likely on a milk-based or liquid supplemental diet, children, adults and then seniors.

Decomposition in Children

As there does appear to be a general trend in the rate of decomposition by age, a further examination was made of the quantitative and qualitative differences in decomposition between age sets. Of particular interest is the extent and rate of decomposition in babies. There are many instances in the forensic context when mothers abandon their babies and a search strategy is needed to recover the remains. In these types of circumstances it is useful to understand what the level of decomposition or preservation will be as time passes in order to design an appropriate search and recovery strategy. If total decomposition can be expected in only a few short weeks, then a search strategy should be designed to located small bones or clothing items as opposed to an intact body with soft tissue.

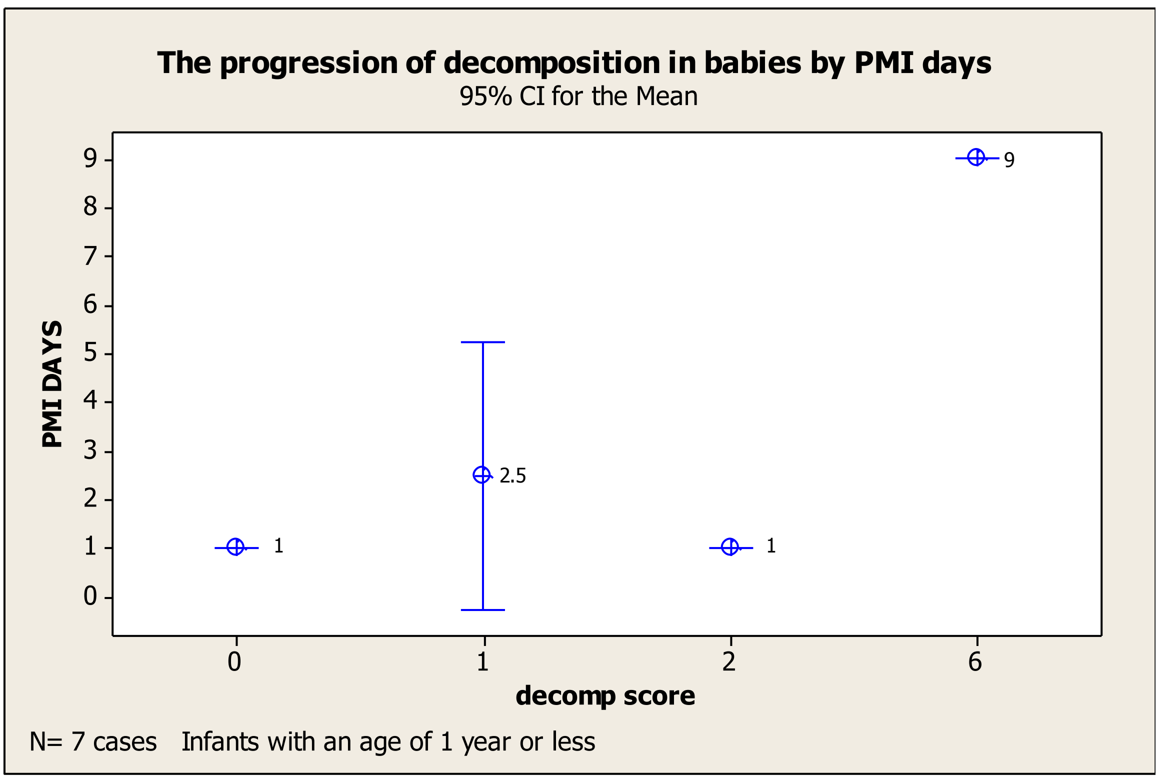


Figure 4.84. The mean PMI days for stages 0 – 2 and 6 for babies under the age of 1 year. The is a minimal progression from stage 1 to 2

There are only 7 babies under the age of 1 year old in this dataset. One of these cases involves an aborted fetus in a clandestine grave. It is only this case which has progressed past the stages autolysis into putrefaction. This is likely due to the underdevelopment of the fetus and the burial environment with the passage of time. For the other six cases none of the other babies progressed past autolysis into putrefaction (Figure 4.84). There are 3 males and 3 females in this group, two suffered head injuries, 3 suffocated and the others died from natural causes. The longest PMI in days is 5 days, however the associated ADD score for that case is zero and the body was outside during cool temperatures. The average PMI for the other five cases is 1.4 days with a mean ADD score of 26.3. The sample size is insufficient to be able to comment on whether or not the rate of decomposition is slower or faster for each stage of decomposition.

What is important to note is the high incidence of mummification in this group. For the general dataset which includes all ages, the percentage of cases with any type of mummification is 10.5% (indoors and outdoors). The rate of mummification for the cases with an age of 1 year or less is 50%. Of the term babies regardless of the PMI interval none of them putrefied but remain in the autolysis stage. The reasons why this is occurring is unknown, however it is hypothesized that the lack of putrefaction may be due to the low frequency of gut flora due to their restricted diet.

At birth the alimentary tract is sterile or contains a limited amount of mirco-organisms (Wilson & Miles 1955). Within a few days of birth, a profuse flora is established in the mouth and large intestine from their mothers and their environment. The amount and complexity of that gut flora increases overtime. Gastric acid acts as the gate keeper for the entry of bacteria into the small intestine. The distribution of bacterial is controlled by the movement of the intestinal contents, type of diet, frequency of feeding and rate of gastric emptying (Drasar et al., 1969). In the small intestine of a healthy child, as in adults, it is usually sterile. According to Anderson et al., 1974, there is likely a mechanism which prevents the growth of Gram negative organisms such as E. *coli* and other ‘faecal types’ until the ilium is reached (*Ibid* 1974:199).

The colonic flora consists of predominantly Gram negative organisms and anaerobes such as *Lactobacillus* and *Bacteroides spp* (Anderson, et al., 1974). The complexity of the gut flora in the large intestine is controlled by diet and by the body (intestinal cells, digestive residues and bilary excretions products) (Drasar 1974). It takes time for the gut flora colonies to mature in an individual. The amount and complexity of the gut flora has an impact on the progression of decomposition during putrefaction. This observation of increased desiccation/ mummification and a delay in putrefaction in babies was confirmed by Dr. Evan Matshes, a forensic pediatric pathologist, working in Calgary, Alberta with extensive experience with infant deaths both in the United States and in Canada (personal communication 2012-09-17, Calgary, AB).

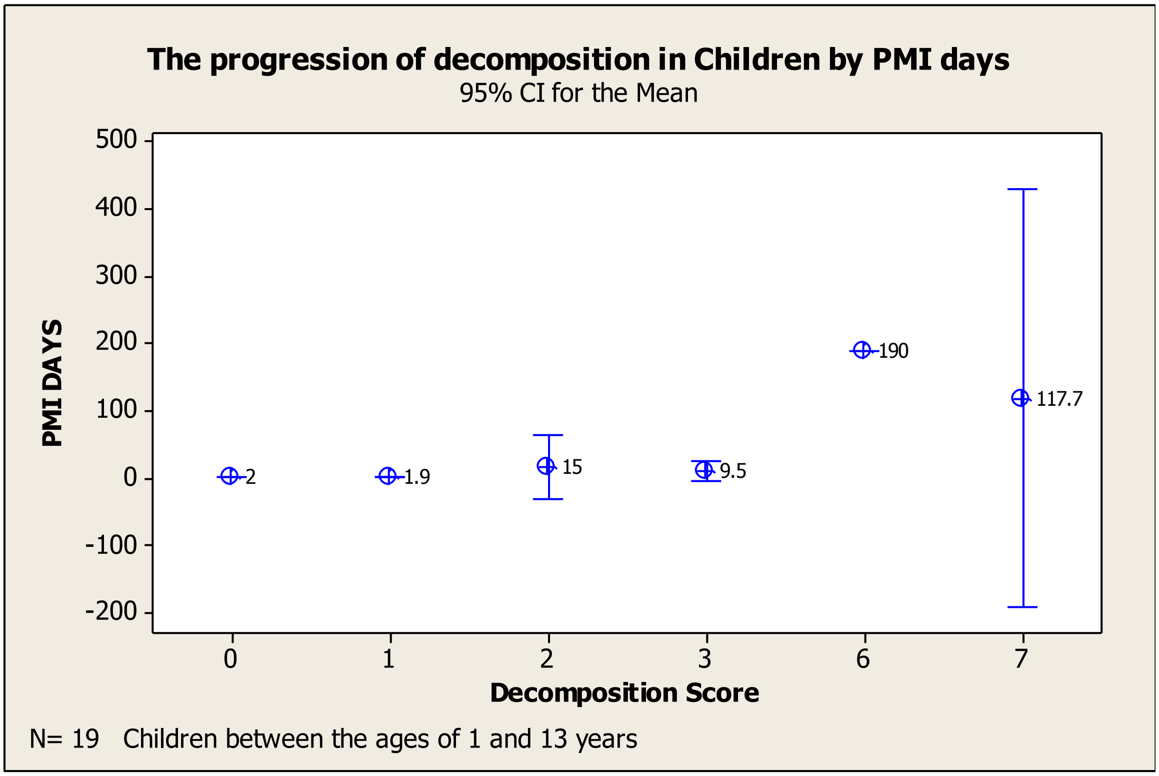


Figure 4.85. The mean PMI days for each stage of decomposition from stages 0 to 7. This group includes all the children between the ages of 1 and 13 years. The progression of decomposition appears to be relatively fast during autolysis and relatively unpredictable past stage 6 and 7.

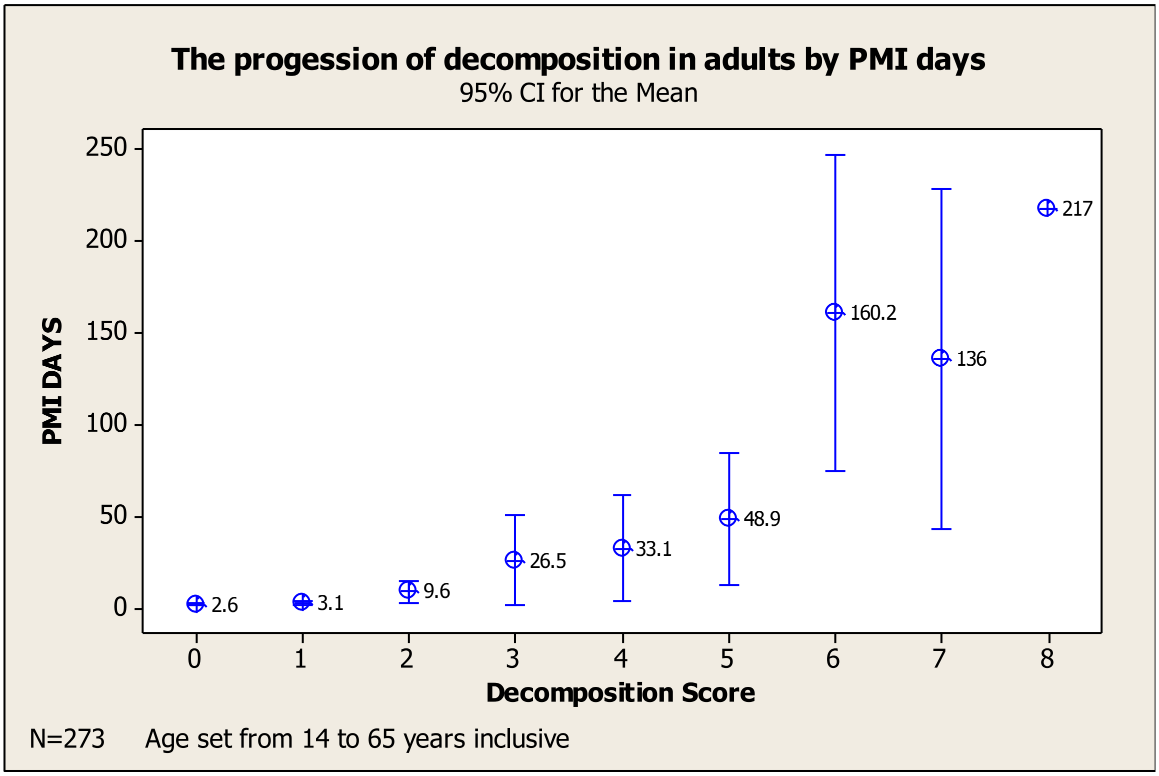


Figure 4.86. ***The mean PMI days for each stage of decomposition for the adult group aged between 14-65 years. There appears to be a relatively predictable progression of decomposition over time for the adult group. The variability increases at stage 6 decomposition.***

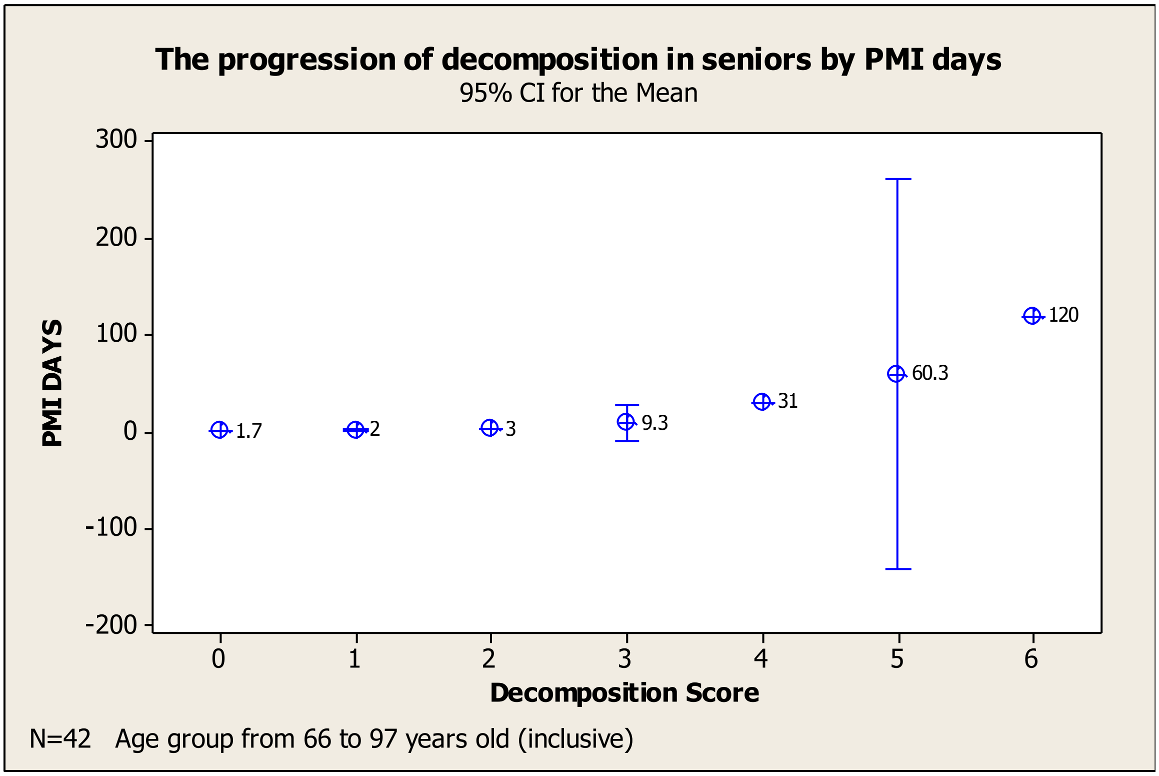


Figure 4.87. The mean PMI days for each stage of decomposition for individuals from 66 to 97 years old. There are lower numbers in this group, however compared to the adult group (Figure 4.86) the rate of decomposition appears to consistently faster.

Table 4.25. This table summarizes the mean PMI days for each stage of decomposition by age group.

Stage of Decomposition	Infant 1 year old or less N=7	Child 1 to 13 years N=19	Adult 14 – 65 years N=273	Senior 66 – 97 years N=42
0	1	2	2.6	1.7
1	2.5	1.9	3.1	2
2	1	15	9.6	3
3	n/a	9.5	22.5	9.3
4	n/a	n/a	33.1	31
5	n/a	n/a	48.9	60
6	9	190	160.2	120
7	n/a	117.7	136	n/a
8	n/a	n/a	217	n/a

Note: n/a = there are no cases in this age set representing this stage of decomposition

Table 4.25 contains the summarized results from Figures 4.85 to 87. These figures show the mean PMI days for each stage of decomposition for the three major age groups of pre-pubescent children (1-13 years) adults (14-65 years) and seniors (66-97 years). The table also includes the results of the data for the infants under 1 year old. Infants, children and seniors all show a generally faster rate of decomposition compared to the adults. The small sample sizes however should be taken into consideration for the results of the two child subsets.

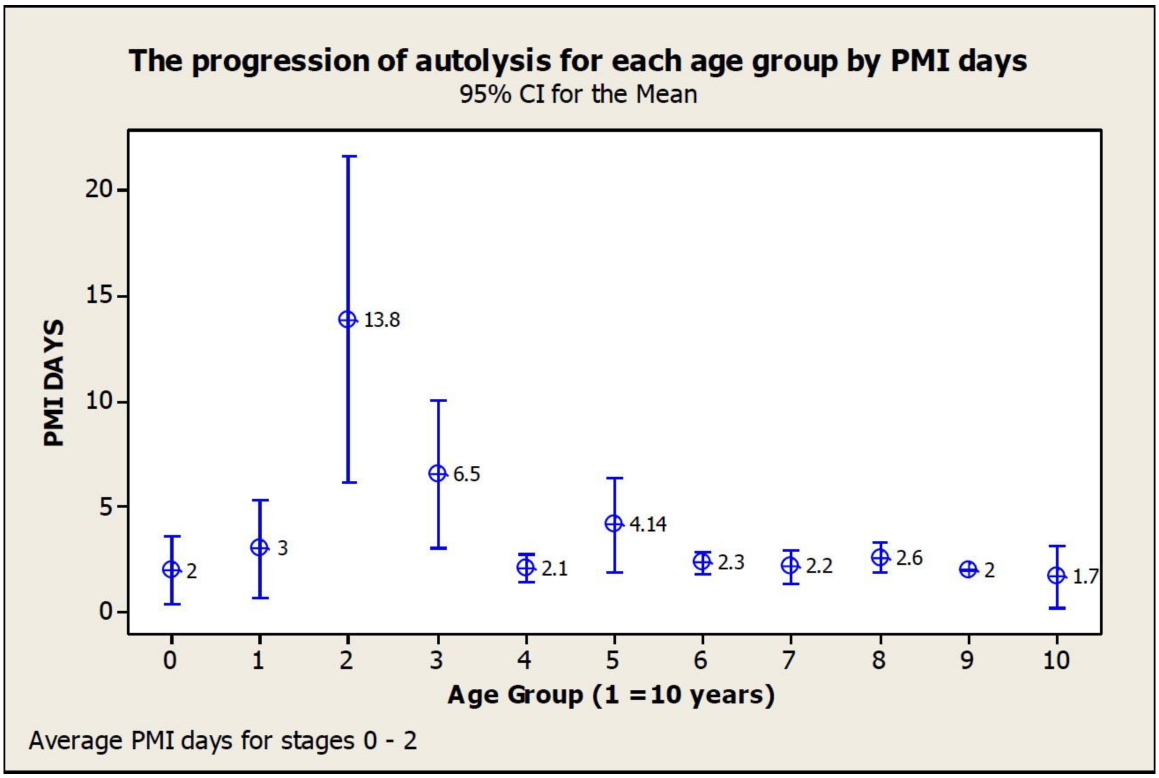


Figure 4.88. The mean PMI days for the progression of autolysis (stages 0 to 2). The cases are divided by age group in sets of 10 years. It appears that the younger the age set, the longer it takes to progress through autolysis. It takes the longest period of time for the individuals in the 20 to 30 year ages set. The results for the age groups from 40 to 100 are similar.

Figure 4.88 provides the summarized data for the mean time it takes for each group to achieve autolysis, which is stage 0 to 2. These cases have not progressed into putrefaction. The cases with an age less than 1 year seem to have a slightly faster rate of decomposition. For the individuals from 40 to 100 years old, there seems to be considerable consistency in the duration of time before putrefaction. What is interesting is the considerably slower and more variable rates of decomposition for the individuals in their twenties and thirties. This variability may not be directly related to their age and could be attributed to other variables affecting this age group. This is the age group with the highest levels of homicide and trauma. The loss of blood as a result of violent death in this instance may be a contributing factor to the slowed rate of decomposition.

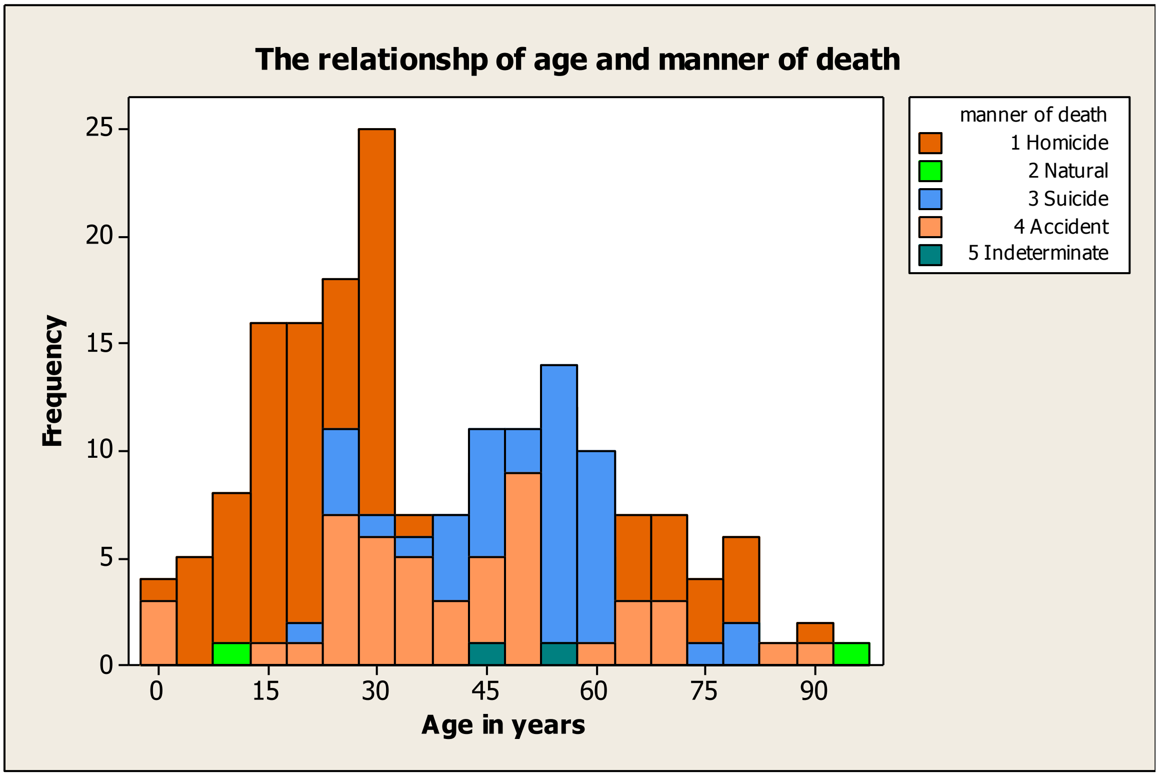


Figure 4.89. The frequency of manner of death is shown by age group. All cases 1 year PMI or less N=341. There is a much higher frequency of homicides in the 10 to 30 age range compared to the adult group. Conversely the adult group (40 to 60) has a much higher incidence of suicides.

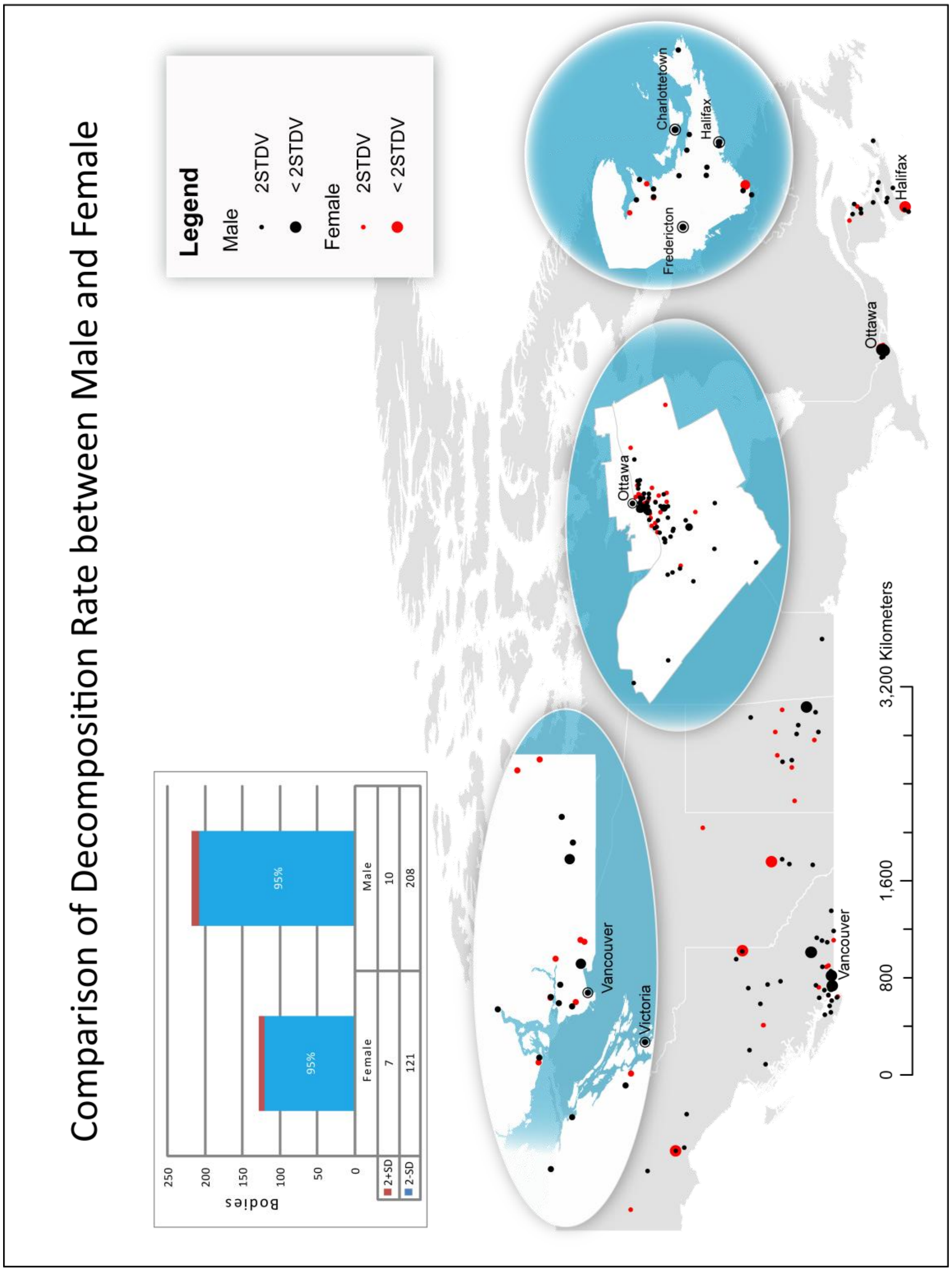
Figure 4.89 shows the concentration of homicides in individuals under the age of 30 years. For the adult category from the age of 30 to 60, the leading manner of death with this age group is suicide. Accidental death appears to be more common in the age group between 20 and 40 years. The impact of violent death and blood loss as it relates to decomposition has been presented in Section 4.2.

The Influence of Biological Sex as a Variable for Decomposition

There are hormonal and structural differences between males and females, it is not known whether these differences translate into quantifiable variances in the process of decomposition. The study was divided into male and female groups and the RLDV used to determine whether or not there was a trend in the relative rate of decomposition between the sexes. The two groups were compared against each other to determine whether there was a difference in the relative rate to achieve a specific stage of decomposition.

There are more males (208) in the study than females (121). As can be seen in the histogram in Figure 4.90, there is an equal proportion of males and females with more than 2 standard deviations from the mean ADD score for all of the stages of decomposition. The distribution of RLDV by male and female does not elucidate any regional pattern across Canada. The map does not identify regions or locations where there is a concentration of male or female bodies with an anomalous rate of decomposition, either 2 standard deviations faster or slower than the norm.

Figure 4.90. ***Distribution and concentrations of RLDV scores by sex across Canada. The histogram shows the same proportion of RLDV scores between the male and female groups. The map does not identify regions or locations in Canada where there is an anomalous rate of decomposition for the male or female groups***



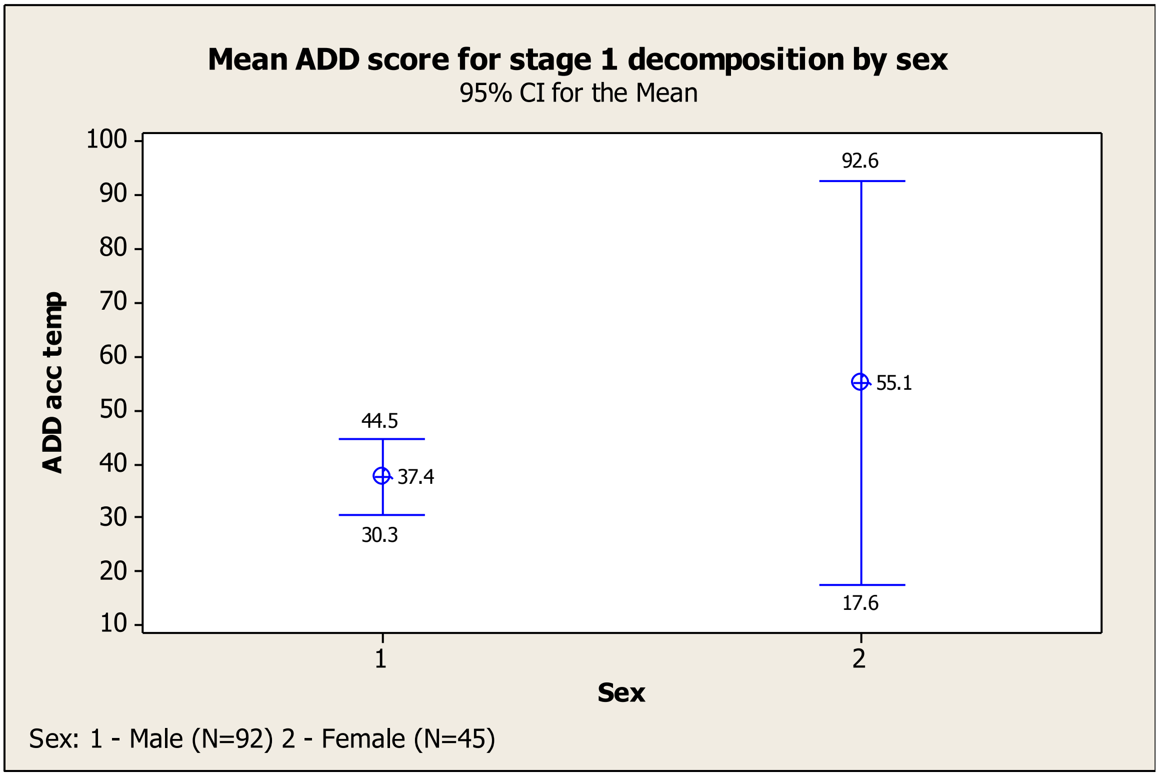


Figure 4.91. ***The mean ADD score for the male and female group at stage 1 decomposition. There is a larger number of males versus females in this analysis. The female group shows the highest level of variability and does show a larger mean ADD score for stage 1 decomposition compared to the male group. The larger mean ADD score suggests more accumulated temperature and potentially more time to achieve stage one compared to the male group.***

Figure 4.91 is a comparison of the mean ADD scores demonstrated by each sex to achieve stage 1 decomposition regardless of the scene type. It should be noted that there is a disproportionate number of males in this analysis compared to females. An increased amount of accumulated temperature is needed to reach stage one for females with a larger degree of variability compared to the male group. When the same analysis is conducted using time as opposed to temperature as the variable, it takes 4.1 days for the female group to reach stage one compared to 2.3 days for males. The error rate is again larger for the female group, which may be attributed to the smaller sample size.

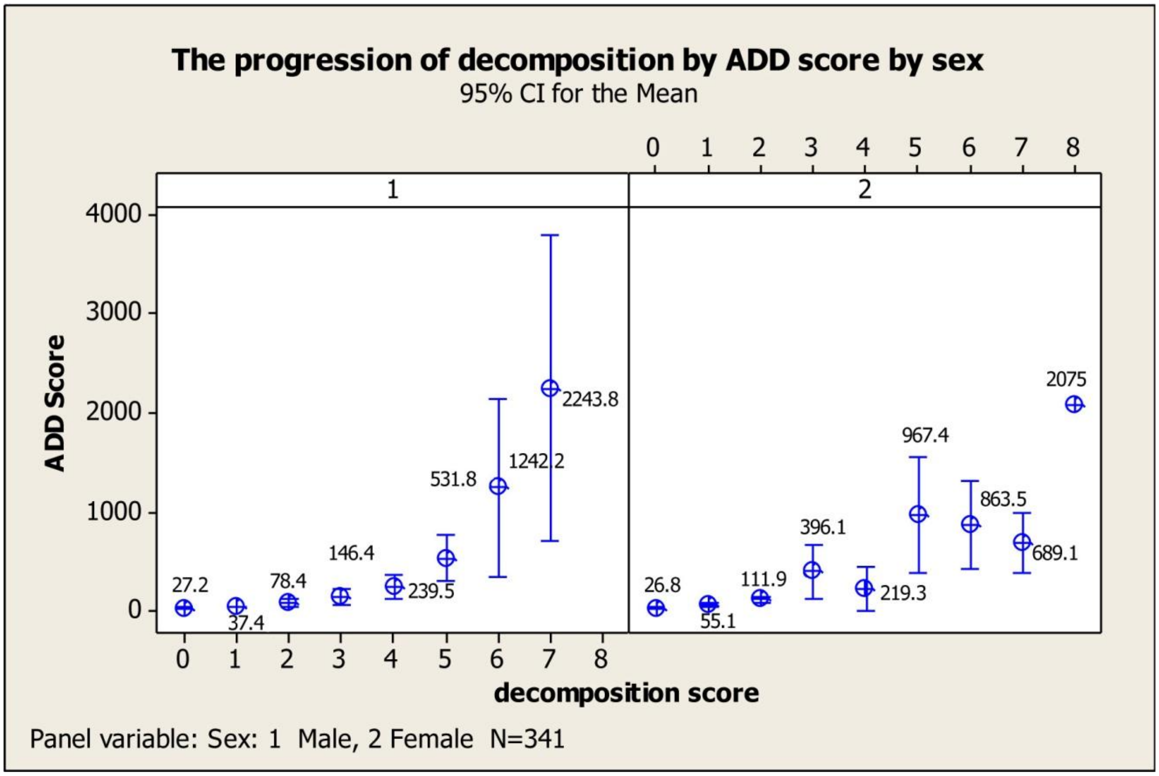


Figure 4.92. The mean ADD scores for each stage of decomposition for the male group(1) and the female (2) group. This analysis was conducted for the all scene types 1 year PMI or less (N=341). The results for the female group show a higher level of ADD scores for autolysis but lower levels for putrefaction. The data does suggest a difference between the progressions of decomposition between the sexes.

The comparison between the average ADD scores for each stage of decomposition for all stages of decomposition in Figure 4.92 does not demonstrate a consistent and predictable difference between the sexes. It does however illustrate that there is a quantitative difference. The results for the female group show a lack of steady progression of mean ADD scores as the decomposition score increases. The male group demonstrates steadily increasing mean ADD scores for each stage of decomposition with increased variability in the later stages of decomposition. The relative rate for females does appear to be different from males for autolysis and putrefaction with an increased variability between male and female. A *t*-test of the mean differences between the groups resulted in a P-value of 0.5 which means that the difference is not statistical significant.

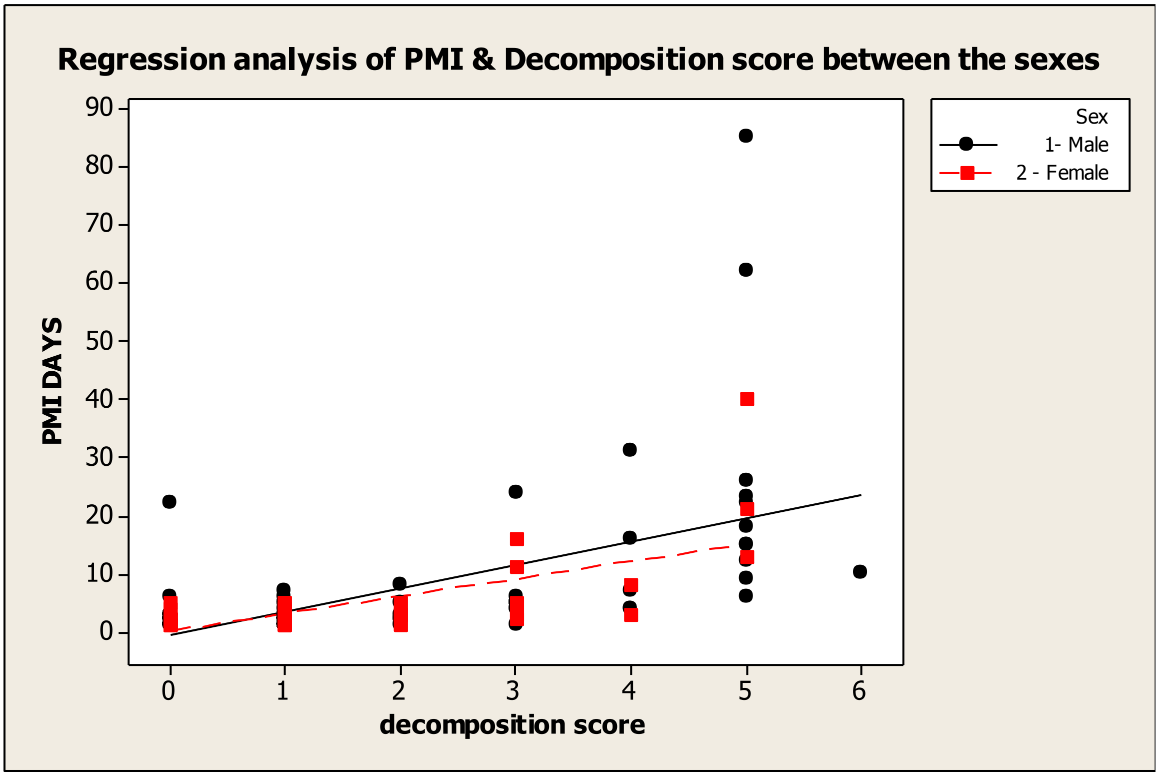


Figure 4.93. The regression analysis between the PMI days and decomposition score for the male and female groups. The results show a slight difference between the two sexes for indoor cases for each sex. Females R^2= 46.3% N=70. Male: R^2= 34.7% N=123

To determine whether context has an impact on decomposition between the sexes, an analysis was conducted for the indoor cases. There is a difference in the regression analysis results for PMI and decomposition score between the two sexes (Figure 4.93), 46.3% for females and only 34.7% for males with a 9.6% difference between the two. Based on the previous Figure 4.92, it seems that these differences are being seen in the later stages of decomposition. When the regression scores are calculated using ADD as opposed to PMI, the difference is slightly less with an R^2= 41.3% for females and 37.1% for males. This is a 4.2 % as opposed to a 9.6 % difference.

Within the outdoor data set, the regression analysis for ADD and decomposition score between the sexes is 36.5% for females and 51.8% for males, a difference of 15.3 % with the correlation being stronger for the males in outdoor cases than for the females, a relationship which seems to be opposite for the indoor cases. If ADD is used as opposed to PMI, then the correlation for females is 32.2% and males 52.9% with a difference of 20.7%. It would seem that there is variability in the accumulated time or temperature between the sexes both inside and outside. These differences however may not be attributed to sex alone.

Build Type as a Variable in Human Decomposition

The classification of body size for each individual was either taken from the ViCLAS or police records or from scene and autopsy photographs.

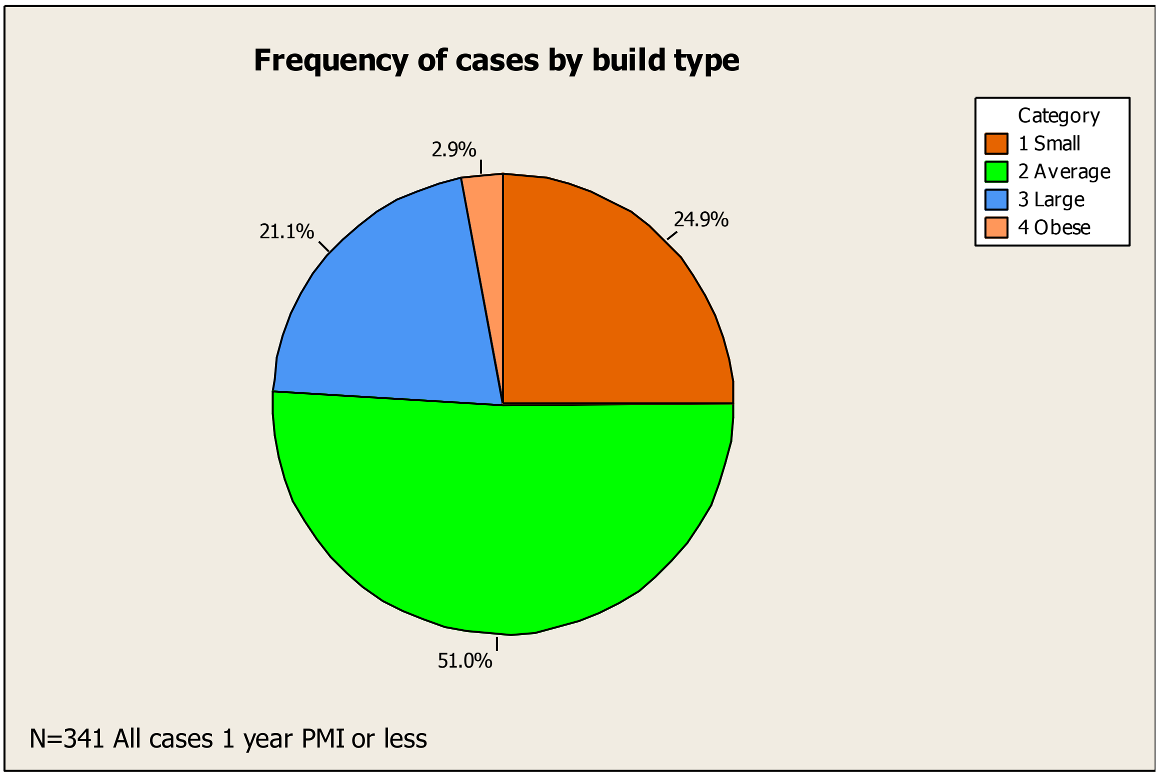
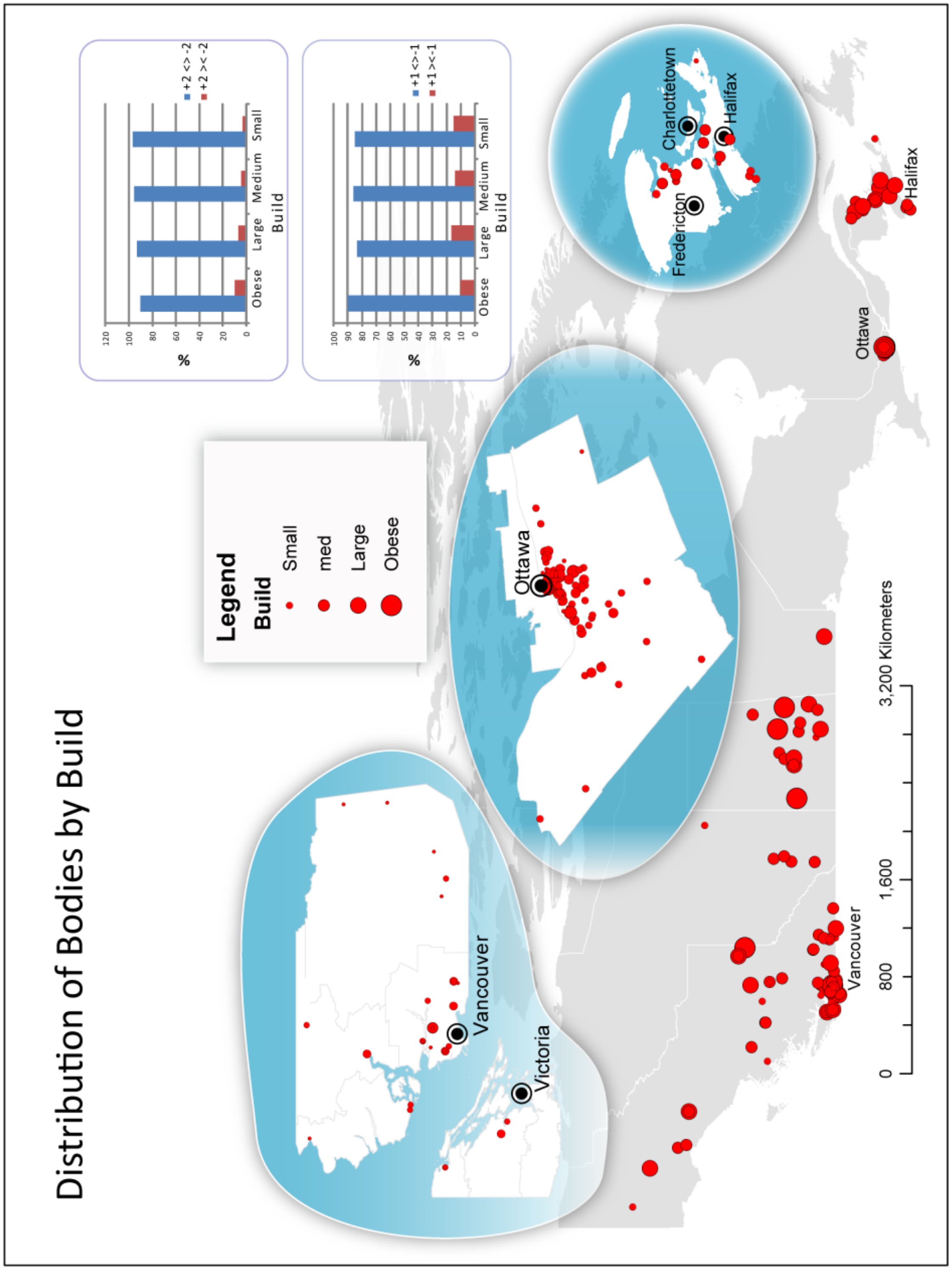


Figure 4.94. The frequency of cases in the dataset by build type. The majority of the cases in the dataset are of average build. There is an equal proportion of individuals who were classified as either large or small build.

The classification of build is based on relative size as opposed to actual weight. Each individual was classified as being: 1- small if they appeared thinner than average; 2 - if of average size; 3 - if larger than normal, and 4 - obese if excessively overweight. The determination of normal is based on the presence of a proportionate amount of body fat and tissue. As is reflected in the normal population, the majority of the body types in

Figure 4.95. Distribution and frequencies of cases by build type and RLDV across Canada



Note: Acording to the historgrams, there does appear to be more obese cases with two standard deviations away from the norm, however theres does not appear to be regional patterning of build sizes across Canada.

the dataset are of normal build at 51 %. This study has represented equivalent percentage of smaller individuals (24.9%) and large and obese (combined 24%) individuals in the dataset (Figure 4.94).

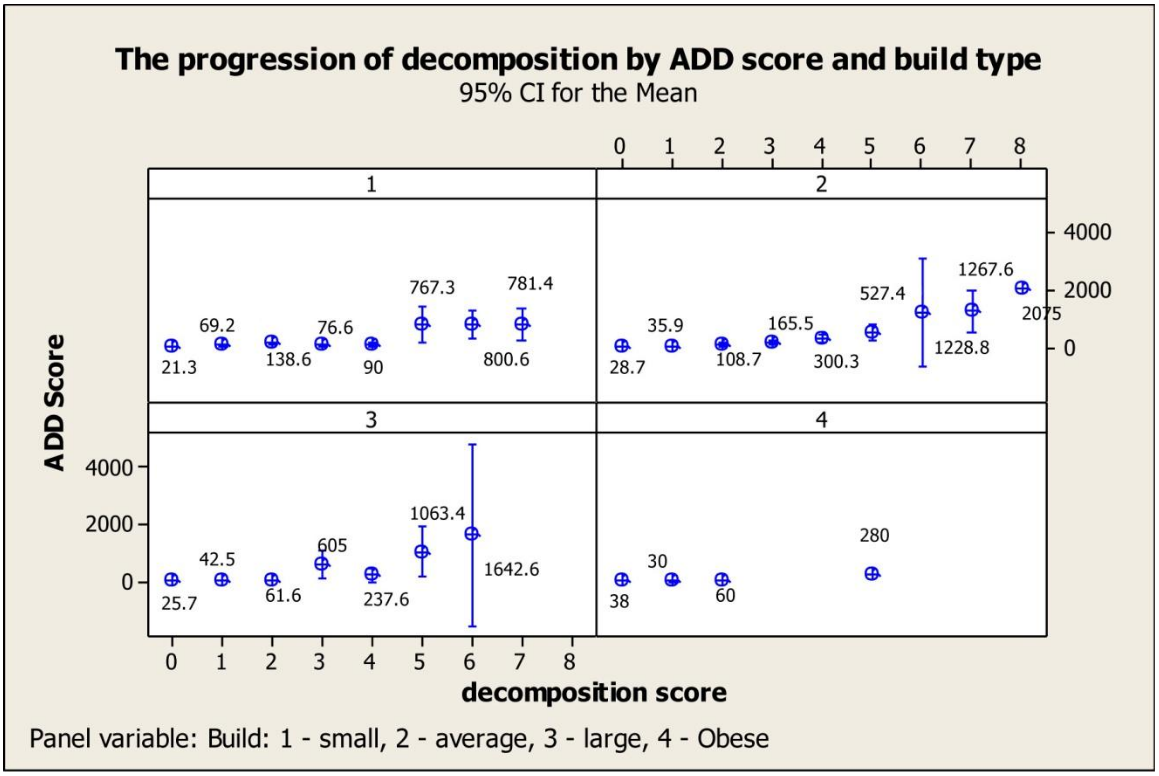


Figure 4.96. The mean ADD scores for each stage of decomposition for the four groups of build type. The groups are small (1), average (2), large (3) and obese (4). N= 341. Due to the low numbers in the obese category, comparisons can only be made between the normal or average group and the small and large groups. The ADD scores for autolysis for all three groups appear to be relatively similar.

Figure 4.95 does show a slightly higher percentage of cases in the obese category with an RLDV of more than two standard deviations. There appears to be a relatively even frequency of cases with an RLDV of one standard deviation by build type. The distribution map does appear to identify a concentration of large to obese individuals in the Halifax area. This result may be representative of the proportions of overweight individuals in the general population in that area.

The individuals who were determined to have a normal build show a steady progression of ADD score for each successive stage of decomposition (Figure 4.96). For the smaller individuals, the average ADD appears to remain constant for the later stages of putrefaction and skeletonization. The average ADD for this body type is generally smaller than the average (2) in the latest stages. A two sample *t*-test of the means for each stage of decomposition between the small group (1) and large group (3) resulted in difference of 0 with a P-value of 0.103 which is not statistically significant. Body size does not appear to be significant independent variable in the progression of decomposition in the Canadian dataset. Body size was a variable which was utilized for the multivariate analysis of decomposition for each scene type. The only stepwise regression which identified body size as a contributing variable was in the outdoor scene type which produced a P-value of 0.006. Body size was one of seven variables which were identified as contributing to 83% of the variability in the decomposition score outdoors.

Manner & Cause of Death

The classification of manner of death is a legal determination based on investigational information and made by the Coroner or Medical Examiner in Canada. These categories include: homicide, accidental, suicide, natural and indeterminate. There are a number of different types of trauma a body can sustain, including: ballistic, sharp and blunt force trauma; strangulation, drowning, suffocation and other. Figure 4.97 provides the frequency of each type of trauma in this dataset. Due to the high numbers of homicides in the database, the most common type of trauma is blunt force (21.4% followed by ballistic (15.4%) and then by sharp trauma (14.3%). The set of cases with ‘other’ or ‘no trauma’ include those individuals who have died of natural causes such as heart attack. The type of trauma can occur in any classification of manner of death. Manner of deaths such as strangulation, drowning and suffocation involve minimal trauma to the body as death is caused by a lack of oxygen. Blunt sharp and ballistic trauma generally results in damage to the body and a degree of blood loss.

The manner of death was converted into nominal data; however it could not be assigned to a progressive scale. The manner and cause of death was examined as it related to blood loss which does have the potential to impact the biological progression of decomposition.

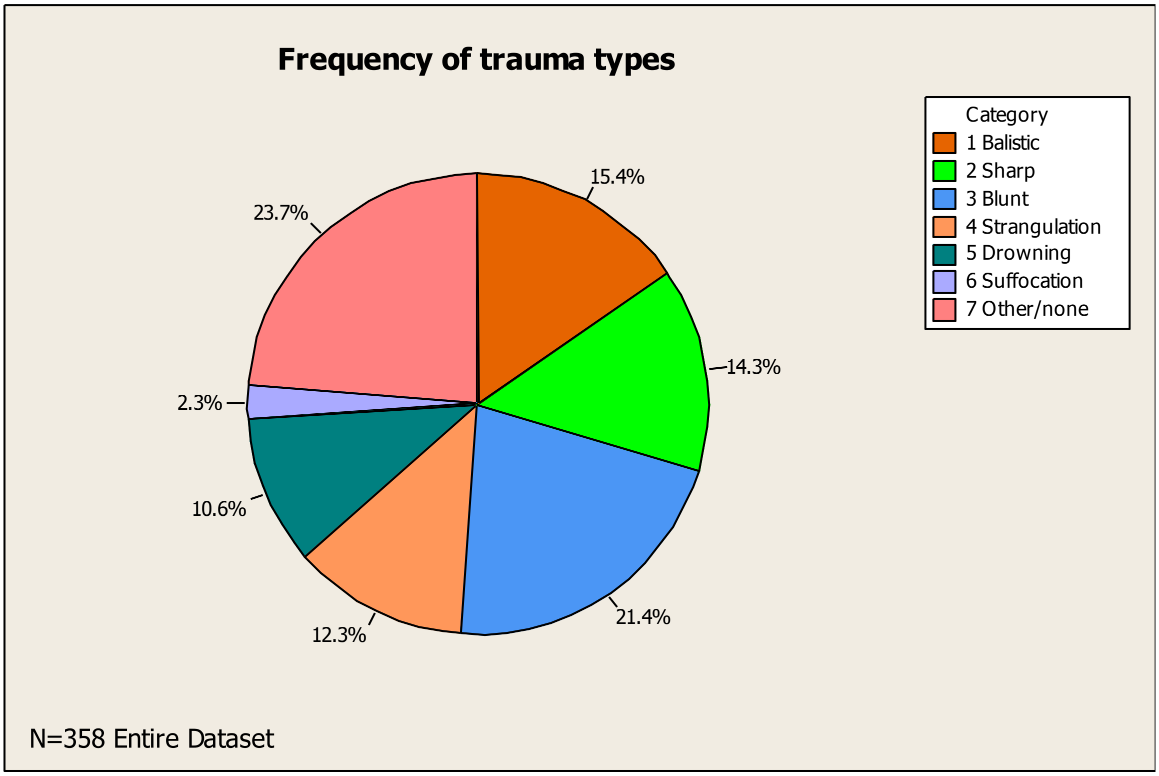


Figure 4.97. ***The frequency of trauma types for all cases in the dataset. The most common trauma type is blunt force trauma. The 'other' category includes death by means other than trauma, such as overdoses or heart attacks.***

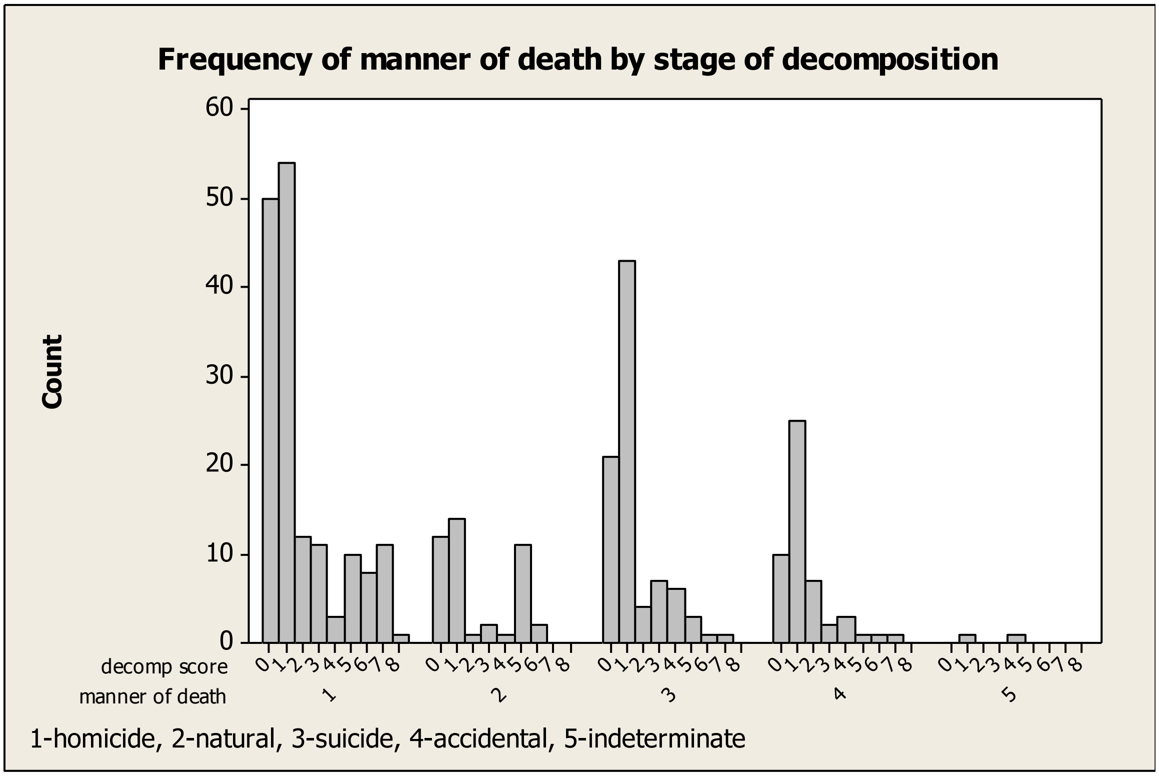


Figure 4.98. The frequency of cases in the dataset (341 cases – indoor, outdoor and water) by manner of death for each stage of decomposition.

As most of the police involved deaths are homicides, the majority of the cases in the dataset are homicides as opposed to suicides, natural deaths or accidents (Figure 4.98). In Canada however, if a death occurs at home and the individual is not in the direct care of a physician, police will attend the scene to determine whether or not it is suspicious. An indeterminate death group includes cases where the mechanism of death cannot be attributed to the decedent (suicide), nature or another person.

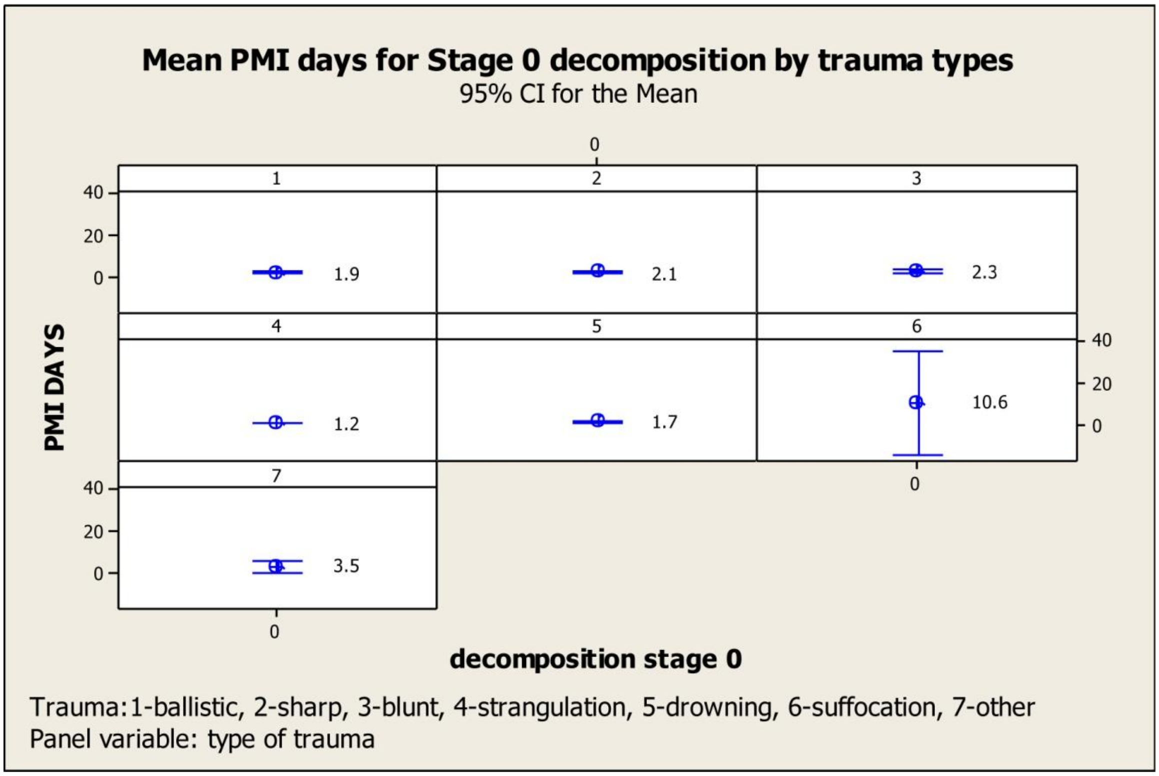


Figure 4.99. The mean PMI days for stage 0 by trauma type

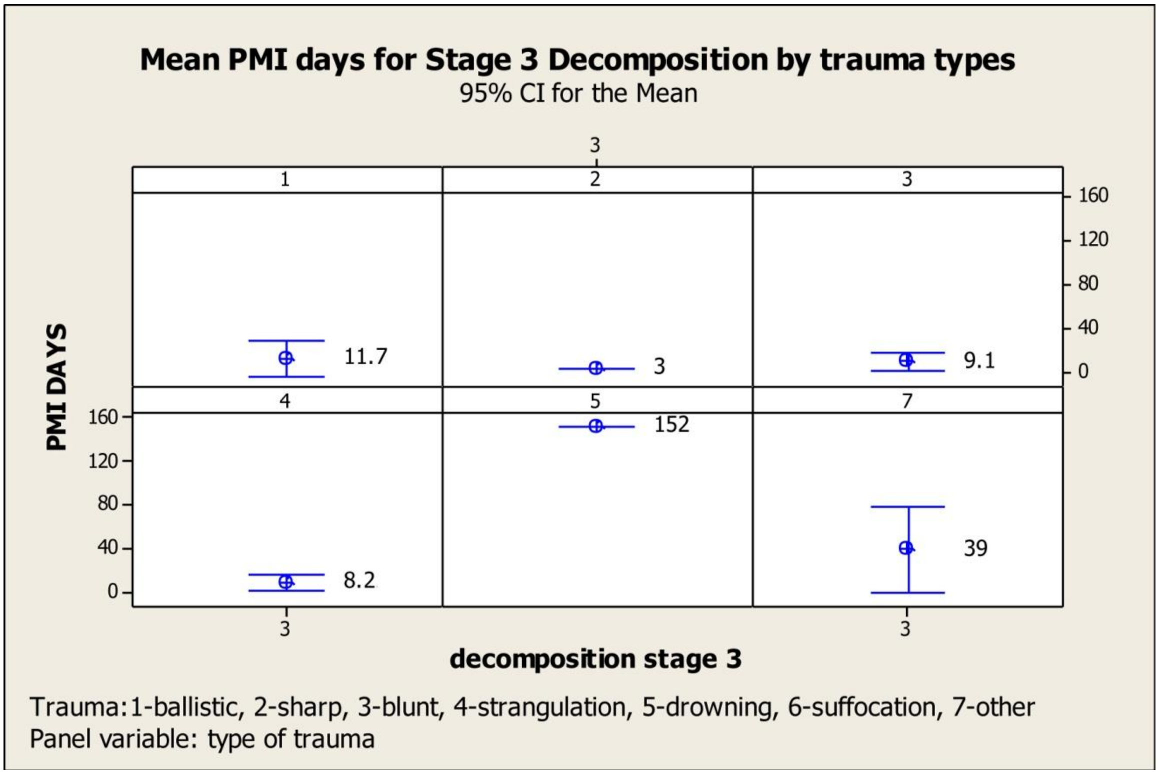


Figure 4.100. The mean PMI in days for stage 3 decomposition for the dataset N=341 with 1 year PMI or less sorted by type of trauma. The group with sharp trauma demonstrated the fastest progression of decomposition and drowning the longest. Many of the drowning cases involve individuals over-wintering in the water body which may explain the extremely large mean PMI in days.

Figures 4.99 and 100 provide a comparison of the mean time it takes to remain in stages 0 (fresh state) and begin the onset of putrefaction at stage 3. For the fresh state of decomposition, there is very little difference in time for the types of trauma except for suffocation. Individuals who have died as the result of suffocation may remain in that fresh state for a considerably longer period of time compared to individuals who have died of penetrative wounds.

For the onset of putrefaction however individuals who have died as the result of sharp trauma appear to achieve stage 3 at a more rapid rate than any other trauma type. Sharp trauma would involve blood loss as well as tissue damage (Figure 4.102). The long PMI duration of the drowning victims is likely due to the over-wintering of bodies in salt and freshwater. Decomposition in water has been demonstrated to take considerably longer than any other scene type.

Blood Loss

Many consider trauma to be very influential in decomposition (Sledzik 1989, Mann et al., 1990, Micozzi 1986). These researchers consider trauma as an influential variable as damage to the soft tissue will increase the access of insect and therefore rate the relative rate of decomposition. Tissue trauma, to the extent it causes death, generally involves blood loss to some extent. It is proposed that the loss of blood is more of a contributing variable compared to tissue damage and increase insect involvement. The impact of blood loss on the biological process of decomposition is not a variable that has so far been investigated in the taphonomy literature. It is suggested that blood loss affects the ability of enteric bacteria to disperse and propagate throughout the body during putrefaction. Blood loss may also equate to lower internal moisture levels which would impact both autolysis and putrefaction.

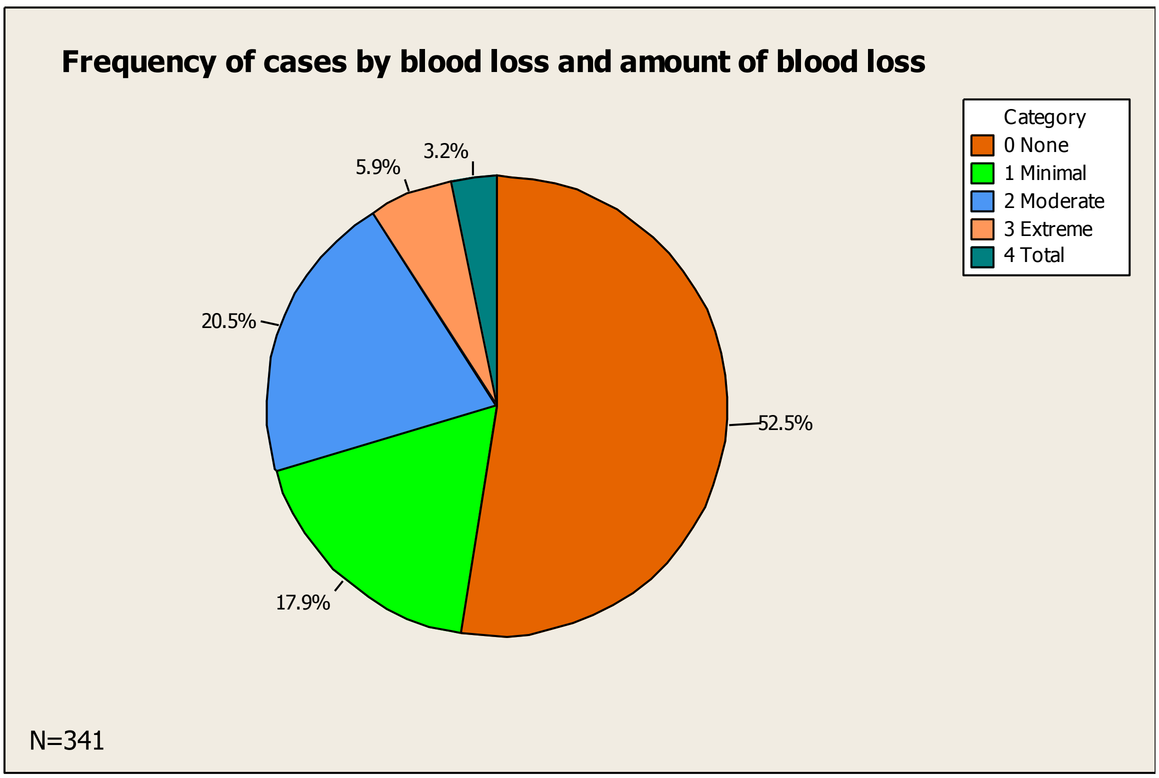


Figure 4.101. The frequency of cases with and without any kind of blood loss. More than half the cases in the dataset have no indication of any blood loss. For the cases with any kind of blood loss, the most frequent amount is a moderate amount with extreme and total blood loss being less frequent.

Depending on body size, we have between 5 to 7 liters of blood in our bodies. A minimal blood loss consists of only a few fluid ounces, which might be seen with superficial tissue damage. Moderate blood loss is defined as an amount of blood between minimal and less than half of the individual's total amount of potential blood with anything up to 2.5 to 3.5 liters of blood. An extreme blood loss is more than 50% of the total available blood, and total blood loss involves complete exsanguination. These estimates were determined for each individual based on relative body size and estimation of blood loss from crime scene photographs.

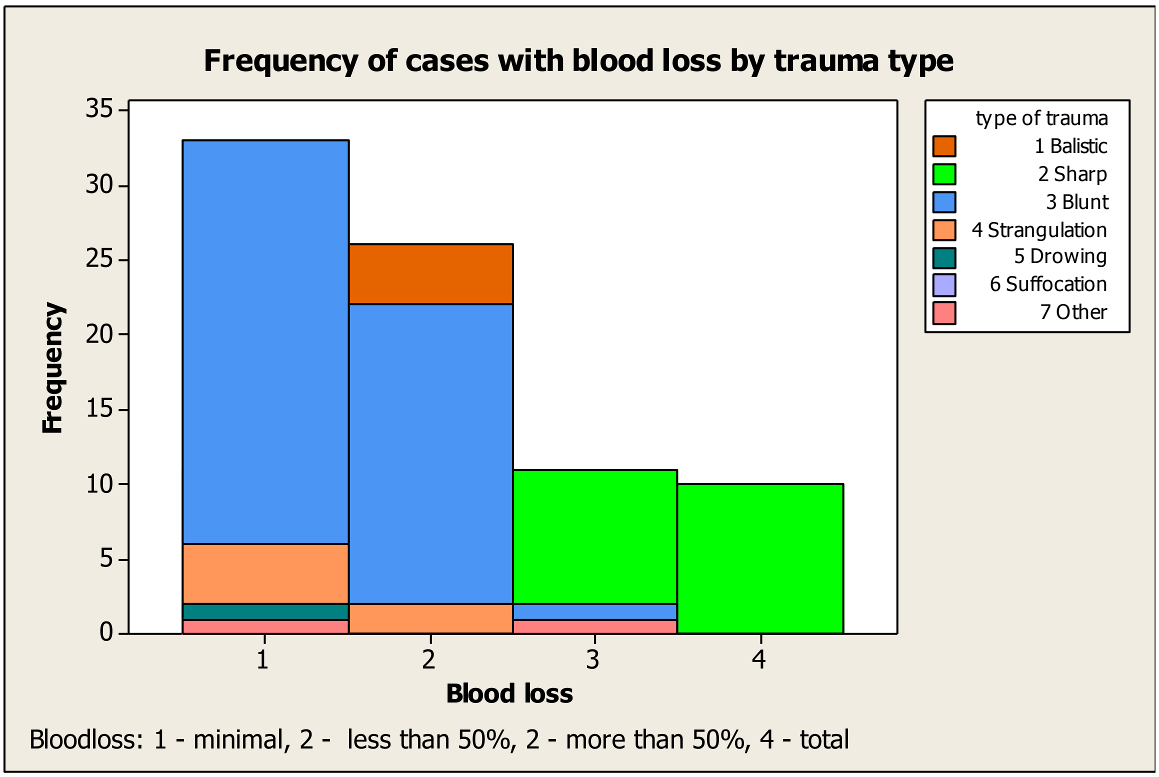


Figure 4.102. The frequency of cases with blood loss according to trauma type. There is an obvious relationship between the type of trauma and the amount of blood loss associated to it. The smaller amount of blood loss is related to blunt force trauma where as higher levels of blood loss is associated to sharp trauma. The greater blood loss and with sharp trauma is likely due to the potential of severed arteries and veins. Blood loss in relation to drowning or strangulation is due to the combination of other trauma types with the main manner or death. Ballistic trauma generally results in a moderate amount of blood loss. N=341

The majority of cases in the data set do not have any kind of blood loss (Figure 4.101). These cases are generally suicides such as hangings and overdoes. There is generally blood loss associated to homicides.

Figure 4.102 demonstrates that blunt force trauma generally results in a minimal or moderate amount of blood loss and sharp trauma will result in more extensive loss of blood. For the ballistic cases in the dataset, the blood loss was less than 50% of the total. For some of the other cases involving trauma such as drowning or other, there was other associated trauma and blood loss which was not the main type of trauma causing death.

In the indoor scenes, blood loss was determined to be a significant variable in the decomposition score with a P-value of 0.009 (Table 4.26). The relationship of blood loss to the progression of decomposition is negative, therefore, the more blood loss, the slower the rate of decomposition.

Table 4.26. Stepwise regression of temperature, blood loss and insects for Indoor cases with 1 year PMI or less: Decomposition score versus ADD Score, Blood loss and Insects

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15			
Response is decomp score on 3 predictors, with N = 191			
Step	1	2	3
Constant	0.9297	0.9151	1.0803
ADD acc temp	0.00489	0.00343	0.00327
T-Value	10.59	7.10	6.82
P-Value	0.000	0.000	0.000
Insects		1.00	1.00
T-Value		6.25	6.36
P-Value		0.000	0.000
Blood loss			-0.170
T-Value			-2.64
P-Value			0.009
S	1.15	1.05	1.04
R^2	37.25	48.05	49.92
R^2(adj)	36.91	47.50	49.11
Mallows Cp	47.3	9.0	4.0

Blood loss was found to be a significant variable in all scene types excluding water scenes either as an independent variable or in a complex of variables (Table 4.33).

The Impact of Drug Use on the Progression of Decomposition

Drugs is a variable that has not been previously investigated as it relates to the impact on decomposition. The presence of drugs and alcohol were examined in a study in New York to help determine the manner of death (Lucas et al., 2002), rather than the influence of alcohol or drugs on the progression of decomposition.

The classification of drug use in this study was divided into two categories, illicit which included currently illegal drugs such as cocaine, heroin or methamphetamine and prescription, which included anti-depressants like Lorazepam or pain killers like oxycotin. When the police and coroner attend the scene, any drug present, illegal or prescription is recorded. This information was made available from the police photographs and coroner and police records. In some instances the drug and alcohol levels in the individual's system was available from toxicology reports. In many instances individuals were known to have been taking a complex of prescription drugs, and in some instances, prescription and illicit drugs. Due to the sheer number and complexity of prescription drugs, only the larger categories of illicit and prescription drugs were used to determine if they had any kind of impact on decomposition.

Figure 4.103 provides the frequency of cases with or without drug use by manner of deaths. There appears to be a higher frequency of illicit drugs related to the homicide victims compared to suicide or natural deaths. The suicide cases have a high frequency of prescription drugs as opposed to illicit drugs. The relationship of prescription drugs such as ant-depressants is expected for the victims of suicide. Of interest, alcohol use is twice as frequent related to homicide as opposed to suicide victims (Figure 4.105).

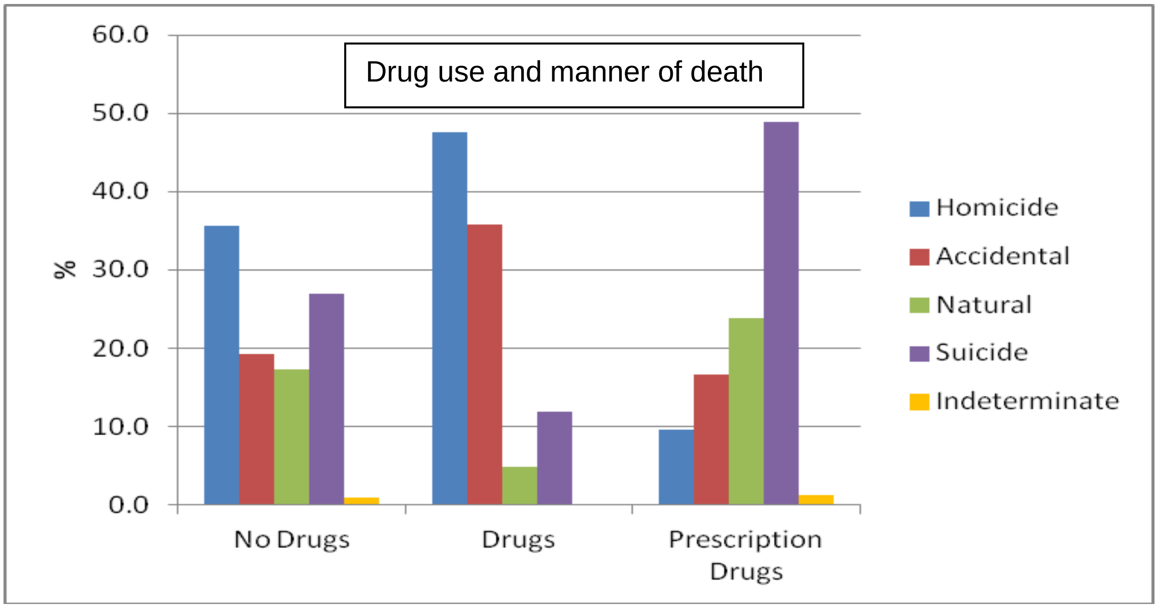


Figure 4.103. The frequency of drug use, either illicit, or prescription divided by manner of death. There is a correlation between the use of illicit drugs and homicide versus prescription drugs and suicide (N=341).

Table 4.27 provides a comparison of the mean ADD scores for each stage of decomposition between the groups of cases known not to have drug use and the groups with illicit and prescription drug use.

Comparisons were conducted for the mean ADD scores for the three groups in Table 4.27 for each of the stages of decomposition. The *t*-test difference between the group without drug use and the group with illicit drugs was not statistically significant with a P-value of 0.542. The difference between the group without drugs and the group with prescription drug use was also not significant with a P-value of 0.234. A comparison between the two drug group sets did not result in a significant difference with a P-value of 0.125. The results of this study, is that drug use was not identified as a predictive variable for the progression of decomposition. Multiple regressions for all scene types removed drugs as a contributing variable to decomposition in Canada.

It was not possible to examine the impact of specific drugs for this study due the sheer numbers of drug types and the size of the dataset. With a much larger database it may be possible to investigate the impact of drug types in more detail. There were insufficient numbers of cases with only ant-biotic use to investigate the impact on the gut flora and subsequent progression of putrefaction.

Table 4.27. The mean ADD scores for each stage of decomposition by presence and type of drugs. N=341

Stage of Decomposition	None	Prescription Drugs	Illicit Drugs
0	22.3	17.2	26.3
1	31.7	43.3	128.9
2	139.8	65.8	168.0
3	431.8	175.0	80.0
4	323.8	103.0	250.0
5	363.5	532.1	747.0
6	1360.4	206.0	845.0
7	668.7	n/a	625.0

N=341 for all cases in the dataset with 1 year PMI or less.

Alcohol Use and Decomposition

The presence or absence of alcohol in a decedents' system at death was scored based on police reports or laboratory toxicology reports. In some instances the exact level of blood alcohol was known, however in most cases, the involvement of alcohol was generally scored as positive or negative. For the case where it was not known if there was or was not alcohol use by the subject, it was scored as 'unknown'. There is no alcohol use for the majority of the cases; however 27% of the cases do have known alcohol use (Figure 4.104).

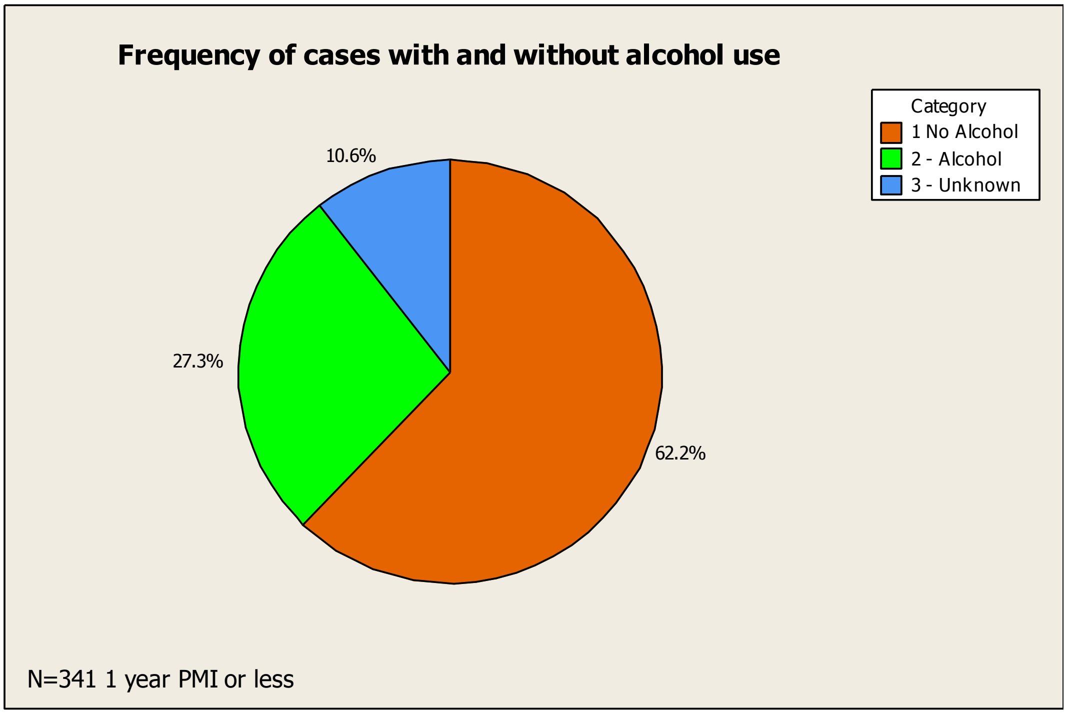


Figure 4.104. The frequency of cases with and without alcohol use. For the majority of the cases in the dataset, alcohol was not used by the decedent immediately before death. A total of 27% of the dataset did have evidence of alcohol use before death. The use of alcohol is not known in 11% of the cases.

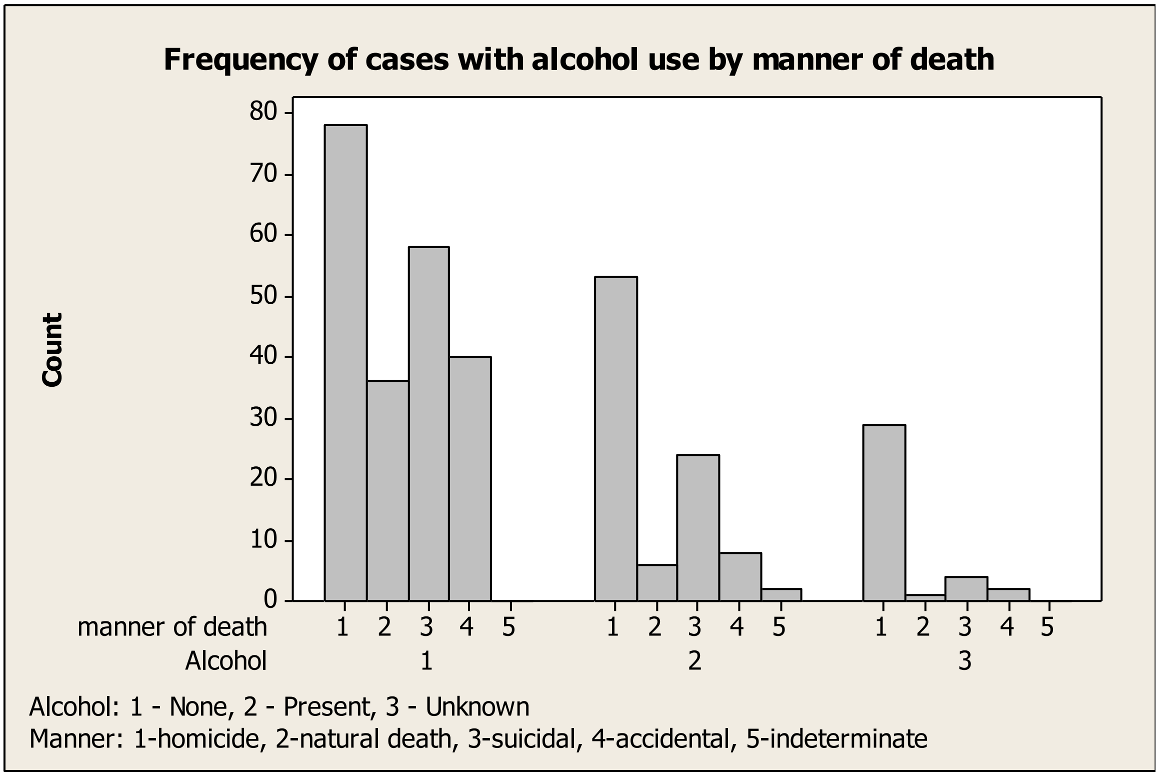


Figure 4.105. ***The frequency of cases with and without alcohol use by manner of death. A comparison between the groups with and without alcohol suggests a correlation between alcohol use, homicide and suicide. There are proportionally more homicide cases in the dataset which accounts for the larger frequency in all three groups of 'none', 'present' and 'unknown'. N=341***

The distribution of alcohol use by manner of death is shown for all case with one year PMI or less (Figure 4.105). There seems to be a much higher use of alcohol with the homicide victims. The use of alcohol by suicide victims is less than half of the homicide group. There appears to be a correlation between higher levels of alcohol and illicit drugs use with the homicide victims.

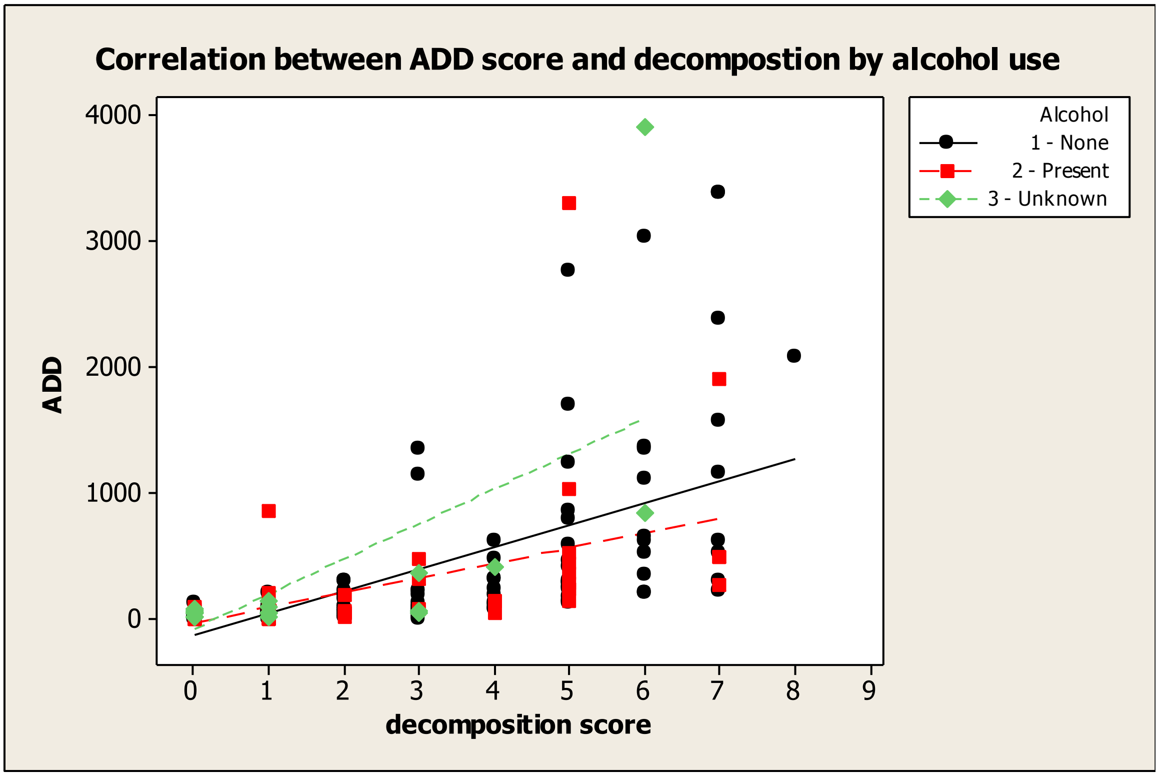


Figure 4.106. The relationship between the ADD score and decomposition score for all three groups by alcohol use. The results are: 1 – No alcohol present: R^2= 43.7%; 2 – Alcohol present: R^2=29.0%; 3 – Unknown alcohol: R^2= 46.8%. The presence of alcohol appears to have a negative relationship with the progression of decomposition by ADD score. N= 341 cases for the three scene types under 1 year PMI

The regression analysis illustrates the relationship between the ADD score and level of decomposition for groups of cases with and without alcohol use (Figure 4.106). The groups with unknown and no alcohol show the relatively normal R^2 result of between 43% and 46%. The group with the alcohol use does show a different relationship with an R^2=29%, which suggests that only 29% of the variability in the decomposition for that group is the result of temperature (ADD score). 71% of the variability in alcohol group is as the result of other variables which exclude temperature.

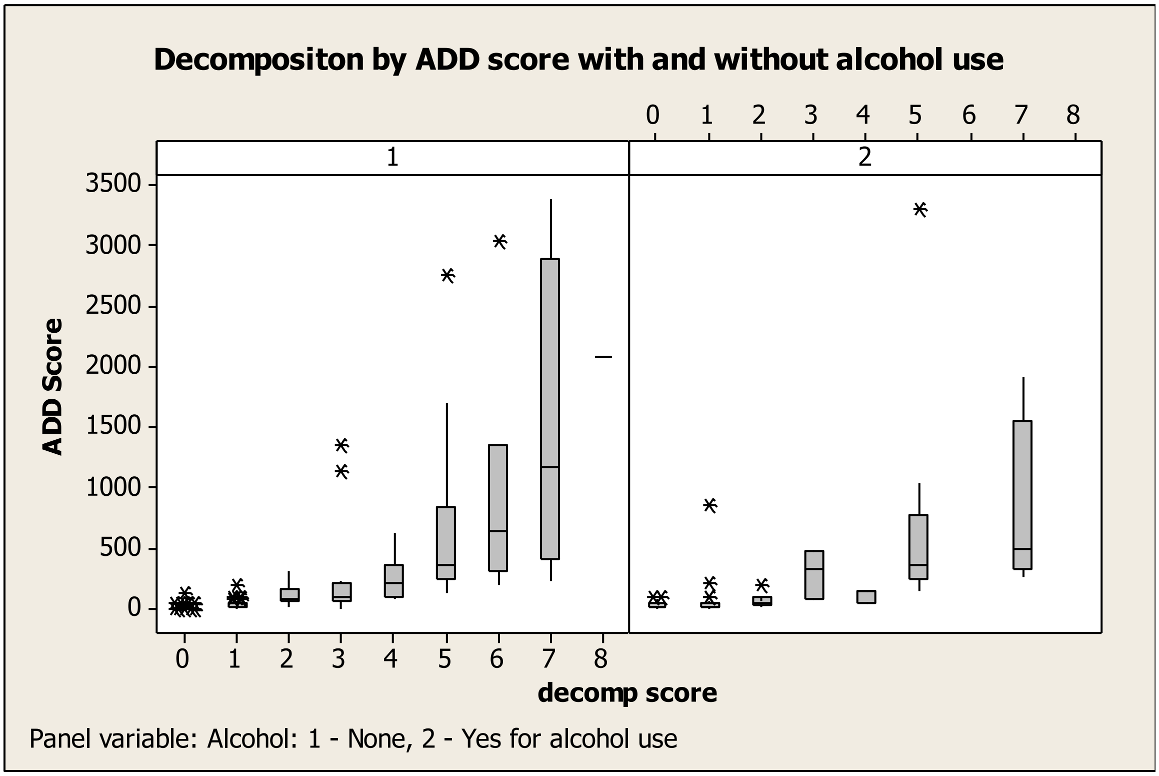


Figure 4.107. The mean ADD score and confidence interval for each stage of decomposition for the group of cases with alcohol use (2) and the group without (1). The group without alcohol (1) shows a normal progress of decomposition with an increasing mean ADD score and an increasing error rate with each stage of decomposition. The group with alcohol use shows an overall slower (lower ADD scores) progression of decomposition. The unknown group has been excluded. N=341

There is a difference in the progression and relative rate of decomposition stage between the group that has alcohol use and the group that does not (Figure 4.107). The group without alcohol use shows a normal progression of mean ADD scores with increasing variability; whereas the alcohol group shows lower mean ADD scores with a lack of predictable progression between the stages. The cause of this deferential in the pattern may be the result of different sample sizes. The alcohol group has a smaller sample size compared the group without alcohol.

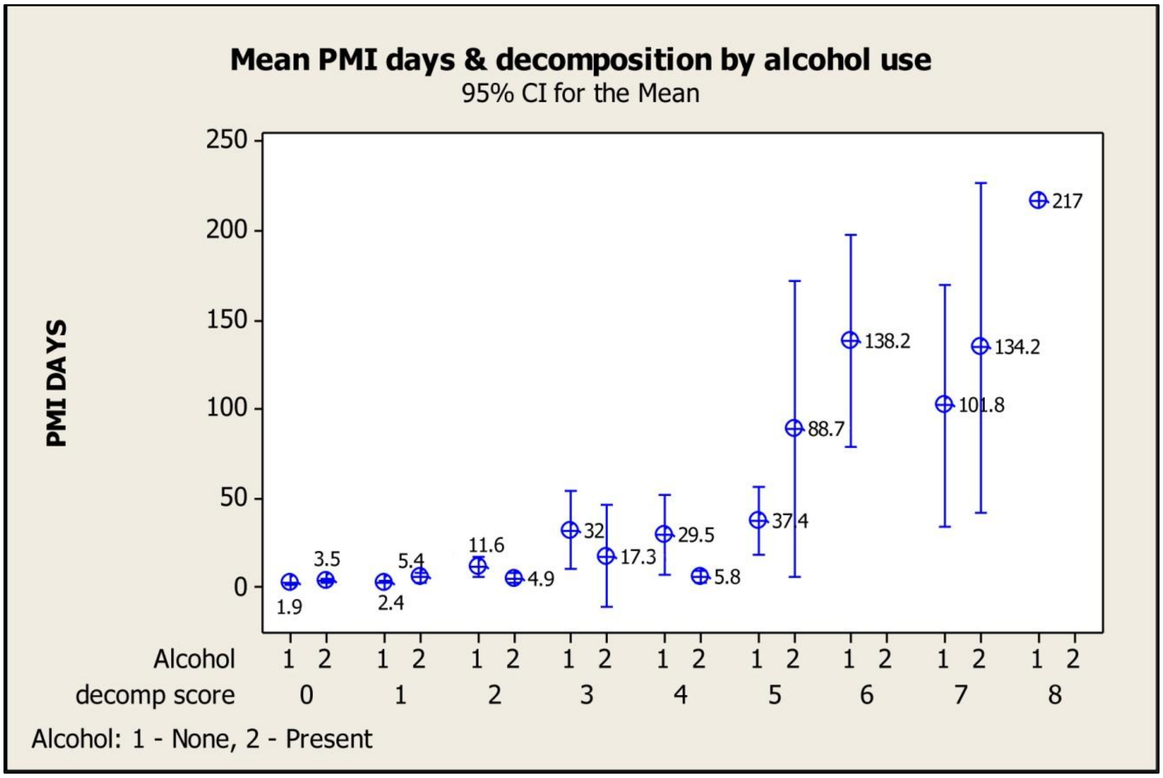
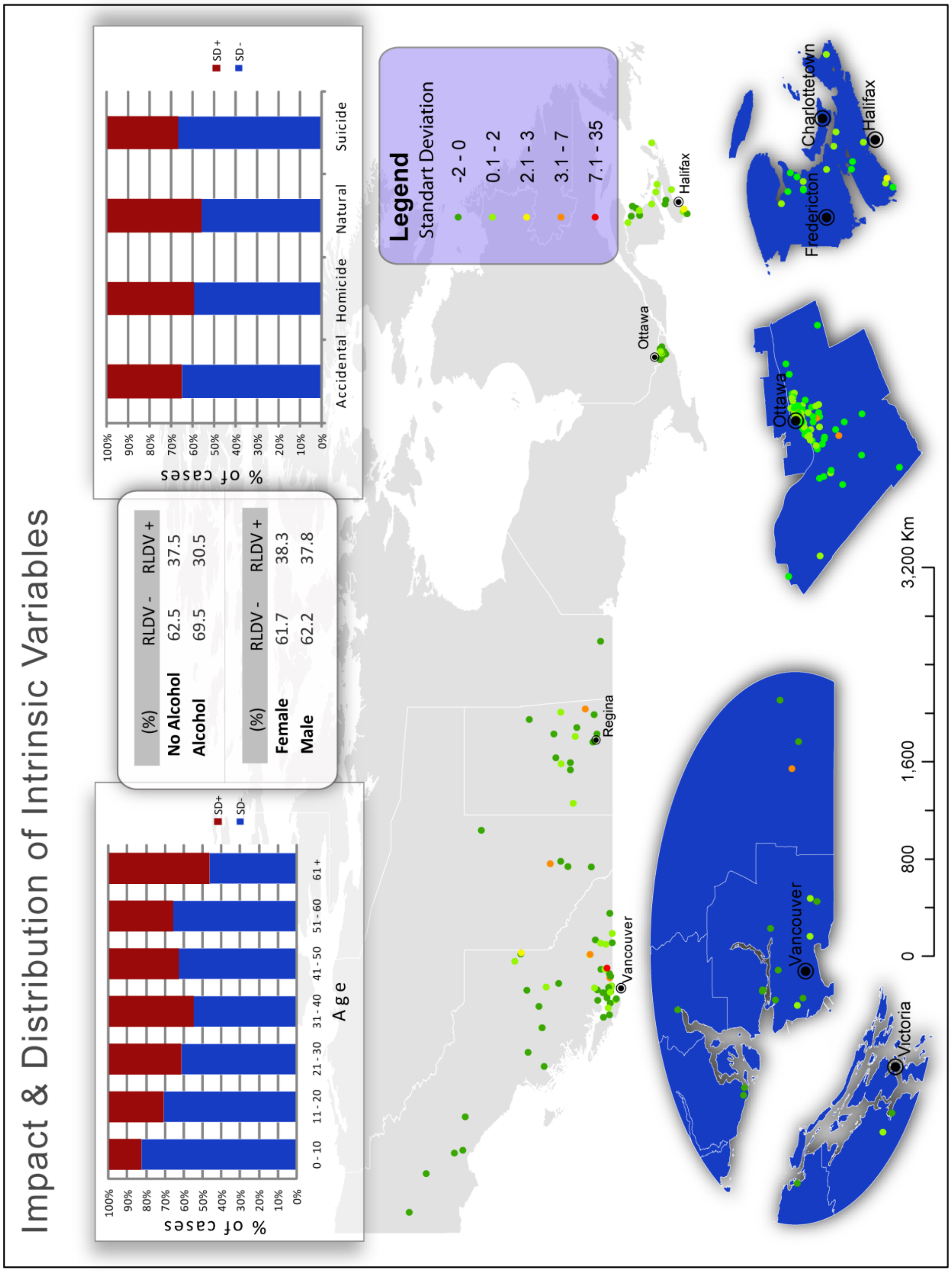


Figure 4.108. The mean PMI days for each stage of decomposition for the two groups with (2) and without (1) alcohol use. The use of alcohol appears to slow down autolysis in stages 0 – 1 but speed up the onset and progression of putrefaction by 50% at stage 2 - 4. Alcohol use appears to impact the duration of stage 5, with bodies with alcohol use in that stage for a considerably longer period of time. N=341

An analysis of the mean PMI days for each stage of decomposition was calculated for the groups with and without alcohol use (Fig 4.108). Alcohol use appeared to have an different impact on each of the three main processes of decomposition. For autolysis, it took just over twice as long (average x 2.14) for the alcohol group to progress along stages 0 – 2 compared to the group without alcohol. However, the onset of putrefaction (stages 3 and 4) in the alcohol group was almost three and a half times faster than the group without alcohol. Even with the faster onset of putrefaction with the alcohol group, liquefaction and skeletonization appeared to take longer with the alcohol group compared to the non-alcohol group. It would appear therefore that alcohol does have an impact on the processes of decomposition.

Figure 4.109. The impact of age, sex, alcohol use and manner of death to decomposition



Note: The histograms show that age and alcohol use does appear to have an impact on the RLDV and relative rate of decomposition. Sex and manner of death does not. The distribution of cases by their RLDV from -2 to 35 does not exhibit any geographical patterning.

The histograms in Figure 4.109 show a generally faster rate of decomposition for younger individuals as opposed the adult group. However there does not appear to be a difference in the frequency of RLDV based on the manner of death. When sex is compared, they show almost the same proportion of RLDVs. There is a difference however between the alcohol use groups with a difference of 7% between the proportions of positive and negative RLDVs. Alcohol use was identified as a predictive variable within the outdoor dataset. It has a negative relationship with decomposition with a P-value of 0.027, (Table 4.28) which is significant. Alcohol use and age are two intrinsic variables which have a measurable impact on the progression of decomposition in the Canadian dataset.

4.3.5. *The Complex of Variables which make the Most Significant Contribution to Variability in the Decomposition Score in the Four Scene Types*

Multivariate analysis was used to evaluate the contribution of variables for the change in the decomposition score for outdoor and indoor cases. Multivariate analysis was also conducted using the buried and water datasets, however due to the small sample sizes, the results should be evaluated with caution. Due to the colinearity of the two variables ADD score and PMI days, they were not included in the same regression analysis, but evaluated separately.

General regression was used to evaluate the combination of environmental, immediate context and intrinsic variables which have been previously identified as having an influence on decomposition, to determine if a complex of these variables could explain the variability in the progression of decomposition for the outdoor surface cases (Table 4.28).

Table 4.28. Regression Analysis for environmental, immediate context and intrinsic variables at outside surface scenes.

General Regression Analysis: Decomposition Score versus Total Precipitation, PMI DAYS, Body size, Scavenging, Insects, Alcohol and blood loss				
Regression Equation				
Decomp Score = 0.528504 + 0.00139838 Total Precipitation + 0.0132417 PMI DAYS				
+ 0.403382 Body size + 1.27761 Scavenging + 1.03925 Insects -				
0.446743 Alcohol - 0.109384 blood loss				
Coefficients				
Term	Coef	SE Coef	T	P
Constant	0.52850	0.414923	1.2737	0.206
Total Precipitation	0.00140	0.001120	1.2487	0.215
PMI DAYS	0.01324	0.004158	3.1844	0.002
Body size	0.40338	0.143093	2.8190	0.006
Scavenging	1.27761	0.163626	7.8081	0.000
Insects	1.03925	0.089218	11.6484	0.000
Alcohol	-0.44674	0.198074	-2.2554	0.027
blood loss	-0.10938	0.088272	-1.2392	0.219
Summary of Model				
S = 0.924572 R^2 = 84.20% R^2(adj) = 82.95%				
PRESS = 92.8010 R^2(pred) = 80.51%				

The analysis identified 7 variables which contributed to the variability in the progression of decomposition outdoors on the surface (N=96). All of the other variables examined during this study were evaluated for their contribution to decomposition using stepwise regression. Variables such as extent of shade, clothing, shroud, age and drug use were removed from the outdoor model due their low levels of significance. Of the seven variables in the model, time (PMI days), scavenging, insects, body size and alcohol have P-Values which make their contributions significant (less than 0.05). For the other variables, including blood loss and precipitation, there is still a contribution; however it is not statistically significant (under 0.2). The extent of blood loss and presence of alcohol have a negative impact on the progression of decomposition. The combination of these seven environmental, immediate context and intrinsic variables were found to be responsible for R^2(adj)= 82.95% of the variability in the stage of decomposition. This result of 83% has a Standard error rate (S) of 0.92 and a Mallows C.P. score of 6.8 with the stepwise regression. The high level of correlation and low error rates creates a model for outdoor surface scenes with a high level of predictive ability. However, it has been previously demonstrated in part I of this study that decomposition has an inherent variability which increases with the stages of decomposition.

Table 4.29. The regression analysis for environmental, contextual and intrinsic variables in indoor scenes (N=177)

General Regression Analysis: decomposition score versus ADD Score and Blood loss				
Regression Equation				
decomp score = 1.12716 + 0.00322211 ADD acc temp - 0.187665 Blood loss + 0.998333 Insects				
Coefficients				
Term	Coef	SE Coef	T	P
Constant	1.12716	0.113511	9.92999	0.000
ADD acc temp	0.00322	0.000494	6.51659	0.000
Blood loss	-0.18766	0.067481	-2.78100	0.006
Insects	0.99833	0.162407	6.14711	0.000
Summary of Model				
S = 1.06176	R^2 = 50.46%	R^2(adj) = 49.60%		
PRESS = 221.309	R^2(pred) = 43.78%			

There are 177 indoor scenes which exclude the bodies in water (bath tubs) (Table 2.29). Of all the variables examined for indoor cases, only the temperature, blood loss and insects had a significant impact on the variability in the stage of decomposition. Blood loss had a negative impact on the progression of decomposition. For the inside scenes, alcohol and body size did not have an impact. There are fewer environmental and immediate context variables affecting indoor cases. The combination of the contribution of temperature, blood loss and insect involvement only contribute R^2(adj)=49.6% of the variability in the progression of decomposition.

There are only 22 buried cases in the dataset. The power of the multivariate analysis decreases and the error rate increases with such a small sample size. The results of the stepwise regression analysis resulted in a much stronger relationship of time with decomposition as opposed to temperature with these types of scenes (Table 4.30). The only other two variables which demonstrated a statistically significant contribution was the level of clothing and extent of blood loss. These three variables are responsible for only R^2(adj)=50.9% of the variability in the decomposition score in buried scenes.

Table 4.30. Stepwise Regression analysis for environmental, context and intrinsic variables for buried bodies outside.

Stepwise Regression: Decomposition Score versus PMI DAYS, Age, body size, alcohol, shade, blood loss, clothing & insects			
Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15			
Response is Decomposition Score on 8 predictors, with N = 22			
Step	1	2	3
Constant	3.402	5.250	6.484
PMI DAYS	0.0125	0.0140	0.0154
T-Value	2.95	3.69	4.32
P-Value	0.008	0.002	0.000
Clothing		-0.74	-0.96
T-Value		-2.54	-3.32
P-Value		0.020	0.004
blood loss			-1.01
T-Value			-2.06
P-Value			0.054
S	2.21	1.96	1.81
R^2	30.37	48.03	57.93
R^2(adj)	26.89	42.56	50.92
Mallows Cp	14.9	8.6	5.9

The results of the regression analysis in Table 4.30 demonstrate that temperature, precipitation, scavenging and insects have little to no impact the progression of decomposition in buried bodies. The two variables clothing and blood loss both have a negative impact on the progression of decomposition. The higher the level of clothing, and the higher the extent of blood loss, the slower the resulting rate of decomposition with buried bodies in the Canadian dataset.

Table 4.31. Step wise regression of environmental, contextual and intrinsic variables for bodies in water scenes.

Stepwise Regression: Decomposition Score versus PMI DAYS, ADD Score, blood loss and Submersion.		
Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15		
Response is Decomposition Score on 4 predictors, with N = 27		
Step	1	2
Constant	1.795	3.189
PMI DAYS	0.0156	0.0153
T-Value	4.70	5.05
P-Value	0.000	0.000
Submersion		-0.62
T-Value		-2.42
P-Value		0.023
S	1.27	1.16
R^2	46.93	57.37
R^2(adj)	44.81	53.82
Mallows Cp	4.8	1.4

The dataset for bodies recovered from water is also limited in size with 27 cases. Due to the small sample size, the results of the multivariate analysis should be viewed with caution. The regression analysis for water scene (Table 4.31) has identified a stronger correlation between time (PMI days) compared to temperature (ADD score) on the progression of decomposition in water. The only other variable which was identified as a contributing variable was the level of submersion. The more the body was submerged, the slower the rate of decomposition. The P-value for this variable is 0.02 which is considered to be statistically significant. The P-value for the PMI in Days is 0.000 which is highly significant. The combination of these two variables only contributes to R^2(adj) 53.8% of the variability in water decomposition.

A regression analysis was conducted for all variables using the total dataset regardless of scene type (Table 4.32). The model identified four variables as significant: time, insects, blood loss and alcohol. These four variables can be correlated to only 61% of the variability in the decomposition score.

Table 4.32. Multiple regression analysis for variables regardless of scene type

General Regression Analysis: decomposition score versus PMI DAYS, Alcohol, blood loss and Insects				
Regression Equation				
decomp score = 1.73879 + 0.0208691 PMI DAYS - 0.350547 Alcohol - 0.149156				
Blood loss + 1.11585 Insects				
Coefficients				
Term	Coef	SE Coef	T	P
Constant	1.73879	0.167554	10.3775	0.000
PMI DAYS	0.02087	0.001253	16.6601	0.000
Alcohol	-0.35055	0.103724	-3.3796	0.001
Blood loss	-0.14916	0.063097	-2.3639	0.019
Insects	1.11585	0.086179	12.9481	0.000
Summary of Model				
S = 1.24959	R-Sq = 61.04%	R-Sq(adj) = 60.58%		
PRESS = 542.698	R-Sq(pred) = 59.70%		N=341	

A summary of the results of the multivariate analysis has been provided in Table 4.33. The temperature was determined to have the biggest impact on bodies inside. Time was a more significant variable compared to temperature with bodies outside on the surface, buried under the ground or in water. Insects played an important part in decomposition both indoors and outdoors. Blood loss and alcohol have been identified as two variables which have a significant negative impact on decomposition in certain scene types. Blood loss and time are the two variables most commonly identified as significant predictive variables for human decomposition in the Canadian dataset.

Table 4.33. Comparison of all variables determined to have an effect on the stage of decomposition by environment.

Variables	Outdoors R^2(adj)=83%	Indoors R^2(adj)=49.6%	Buried R^2(adj)=50.2%	Water R^2(adj)=53.8%	All Scenes R^2(adj)=61 %
Time (PMI days)	✓ +		✓ +	✓ +	✓ +
Temperature (ADD)		✓ +			
Precipitation	✓ +				
Scavenging	✓ +				
Insects	✓ +	✓ +			✓ +
Body Size	✓ +				
Alcohol	✓ -				✓ -
Blood loss	✓ -	✓ -	✓ -		✓ -
Clothing			✓ -		
Submersion				✓ -	

Note: The "+" represent a positive relationship with the progression of decomposition, the "-" represents a negative relationship.

It is the outdoor surface scenes that show the greatest level of predictability with seven variables contributing to 83% of the variability in the decomposition score. The model created for the three other environments show a low level of predictive ability with the variables identified. More than half of the variability in the decomposition score for inside, water and buried cases cannot be explained by the range of variables identified by this study.

4.4. Part III: The Geographic Variability of Decomposition in Canada

This section presents the results of the examination of the regional or geographical variability of decomposition within Canada. The RLDV for each case and the geographic distribution of those values across Canada were used to examine regional diversity. Due to sample sizes, only cases from the two main ecozones; Pacific Maritime (13) and MixedWood Plain, (8) were used to identify variability in decomposition caused by ecological diversity. The two questions that this section will attempt to answer are:

1. Is there a quantifiable difference in the time or temperature it takes progress along the stages of decomposition between two ecozones of Canada?
2. Is it possible to associate certain types of alternate states of decomposition to specific geographic or ecological regions of Canada?

The frequency of cases from each Province or Territory in Canada is not representative of homicide or death rates, but logistical access to investigative files (refer to sections 3.2.2. and 3.2.3 of the methods chapter). The two provinces with the largest representation in the study are British Columbia and Ontario. Although there are only two main provinces in the study, the population within these two provinces represents more than half of the population of Canada (Figure 4.110).

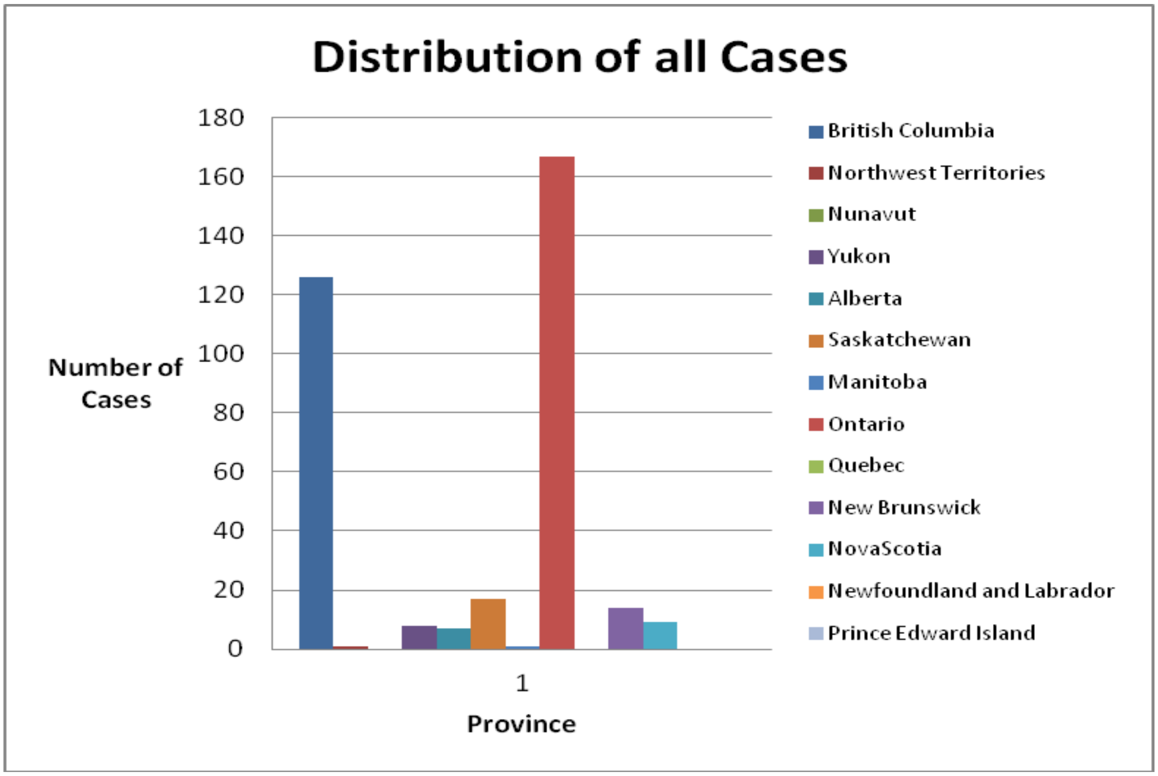
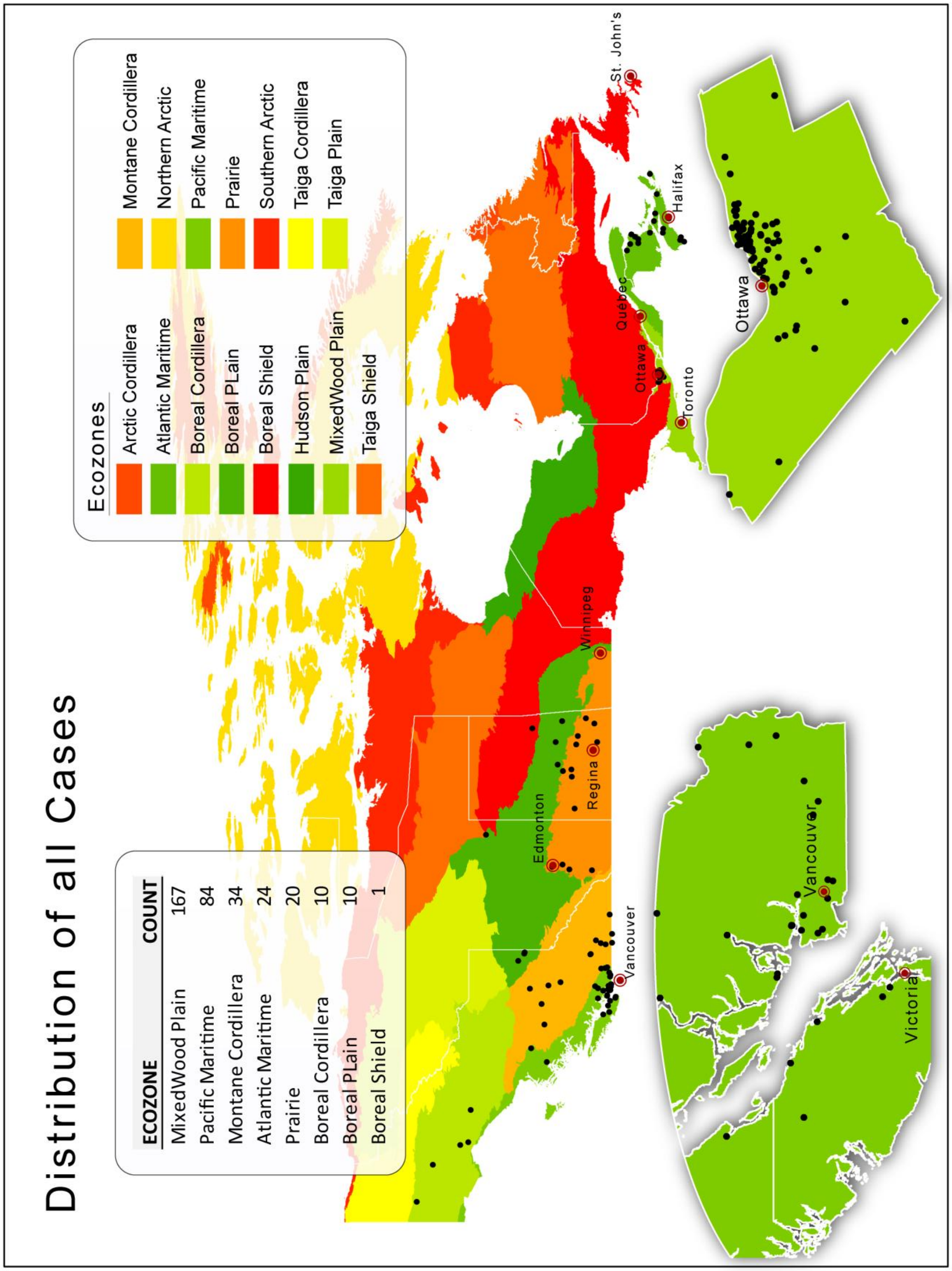


Figure 4.110. The relative frequency of cases in the dataset by Province or Territory in Canada. British Columbia (blue) and Ontario (red) have the highest number of cases. All of the Ontario cases are from the Ottawa region. Quebec, Nunavut and the rest of Ontario are not represented.

The cases were classified by ecozone and ecodistrict. Figure 4.111 shows the distribution of cases in Canada by ecozone. The cases in this study represent 8 out of the 13 ecozones in Canada. Cases in the ocean were associated to the closest terrestrial ecozone.

Figure 4.111. Distribution of cases by ecozones in Canada



Note: The majority of the cases are located in British Columbia (Pacific Maritime) and Ontario (MixedWood Plain).

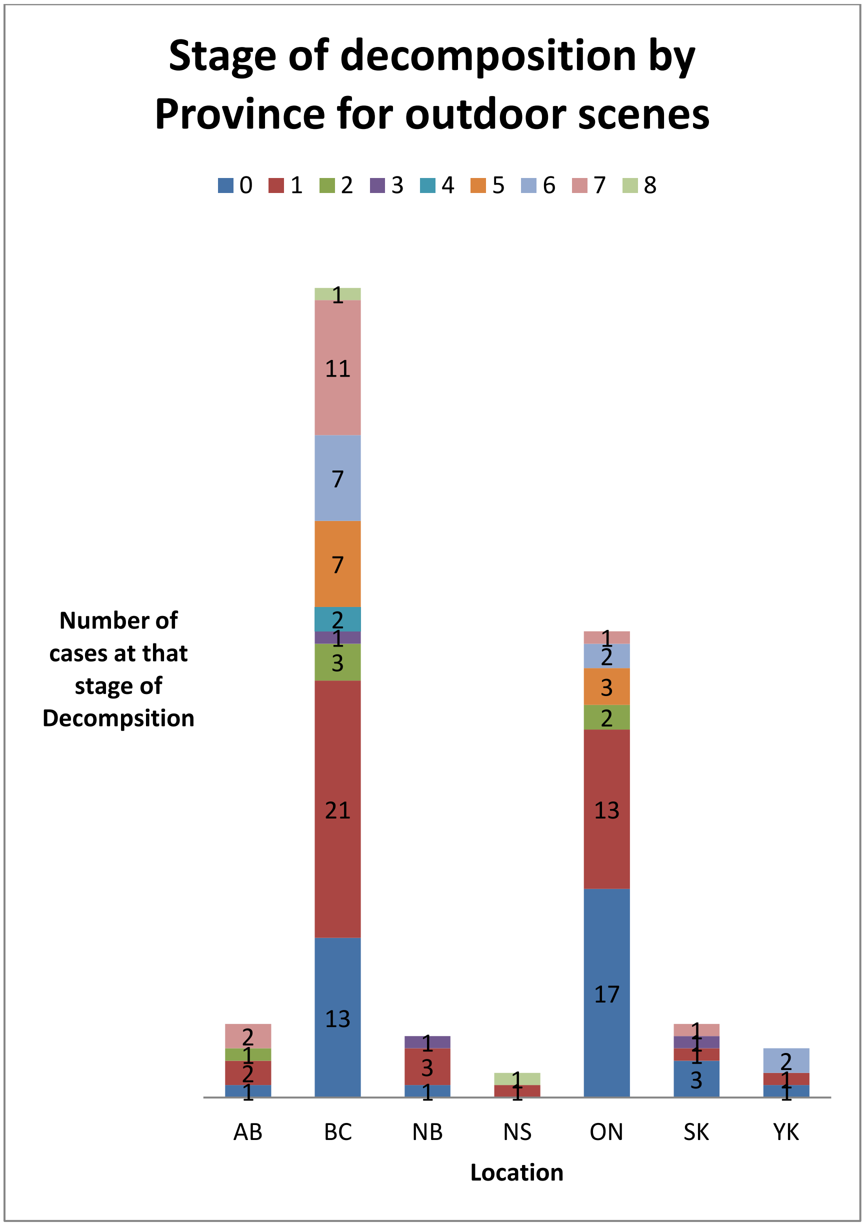


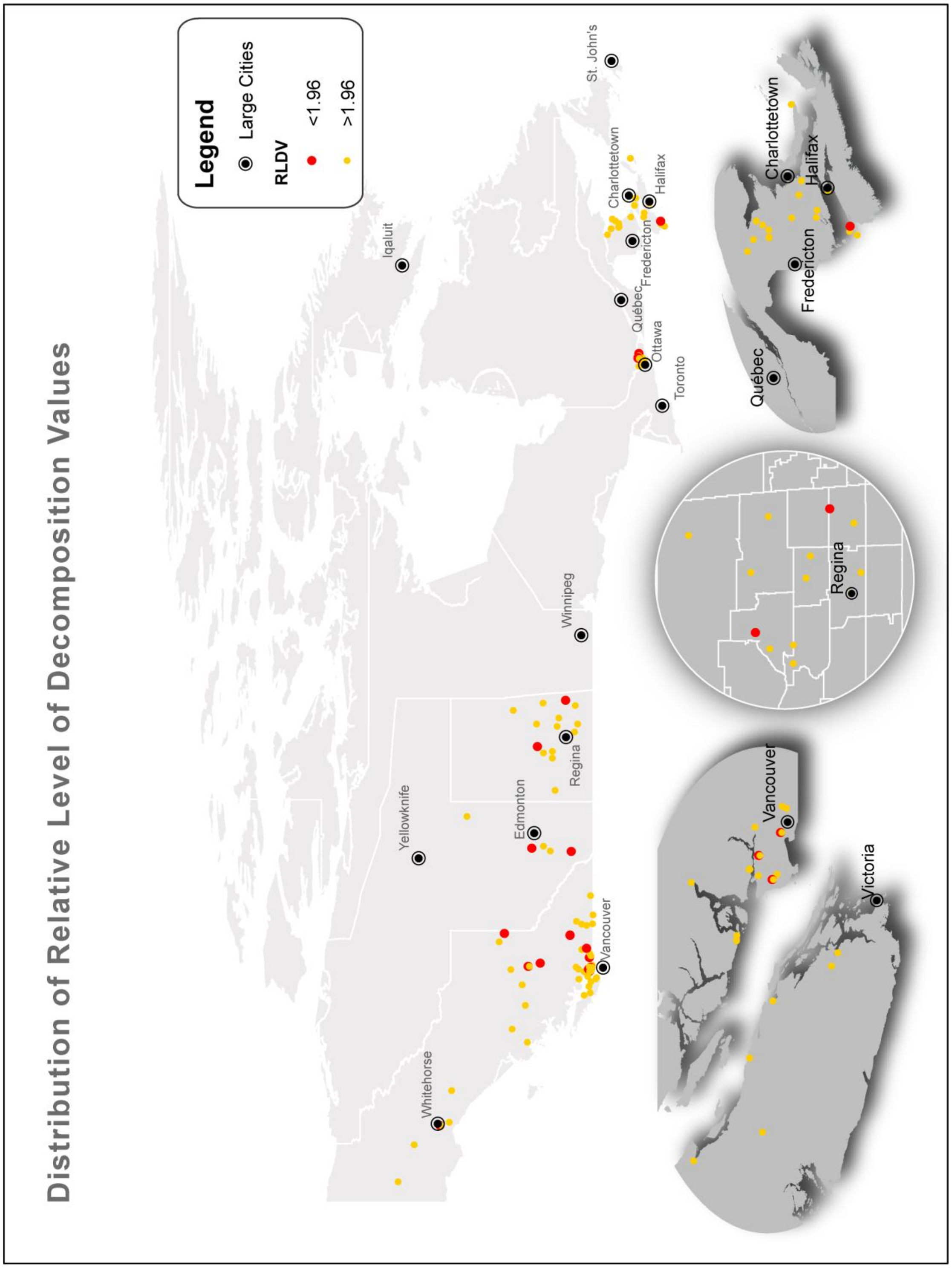
Figure 4.112. The frequency of cases at a certain stage of decomposition by Province for the outdoor scenes. British Columbia (BC) has the most cases and the best representation of stages.

There is a much better representation of early stage decomposition in all regions compared to the later stages of putrefaction and skeletonization (Figure 4.112). This is related to the earlier discovery of bodies in populated regions. With a higher population density, the opportunistic discovery of a body outdoors increases. Discovery of a body indoors generally occurs sooner than a body outdoors.

4.4.1. *The Regional Distribution of RLDV*

GIS was used to plot the distribution of the cases with their associated RLDV within Canada. For the purposes of the map, the RLDV for each case has being assigned as either less than (red), or more than (yellow) the mean. The mapping of the distribution of RLDV was intended to identify geographic clustering of either positive or negative values (Figure 4.113). Cases which are more than one standard deviation above the mean ADD score for their specific stage of decomposition and scene type are shown in yellow, the cases that fall one standard deviation or more below the mean are shown in red. A red dot would therefore represent a case with a faster rate of decomposition compared to other comparable cases. The majority of the cases are on or above the standard deviation. There does not appear to be any geographical clustering of red or yellow cases across Canada.

Figure 4.113. The distribution of RLDV across Canada. Red represents the lower values and yellows the higher values. There does not appear to be any regional clustering of RLDVs across Canada.



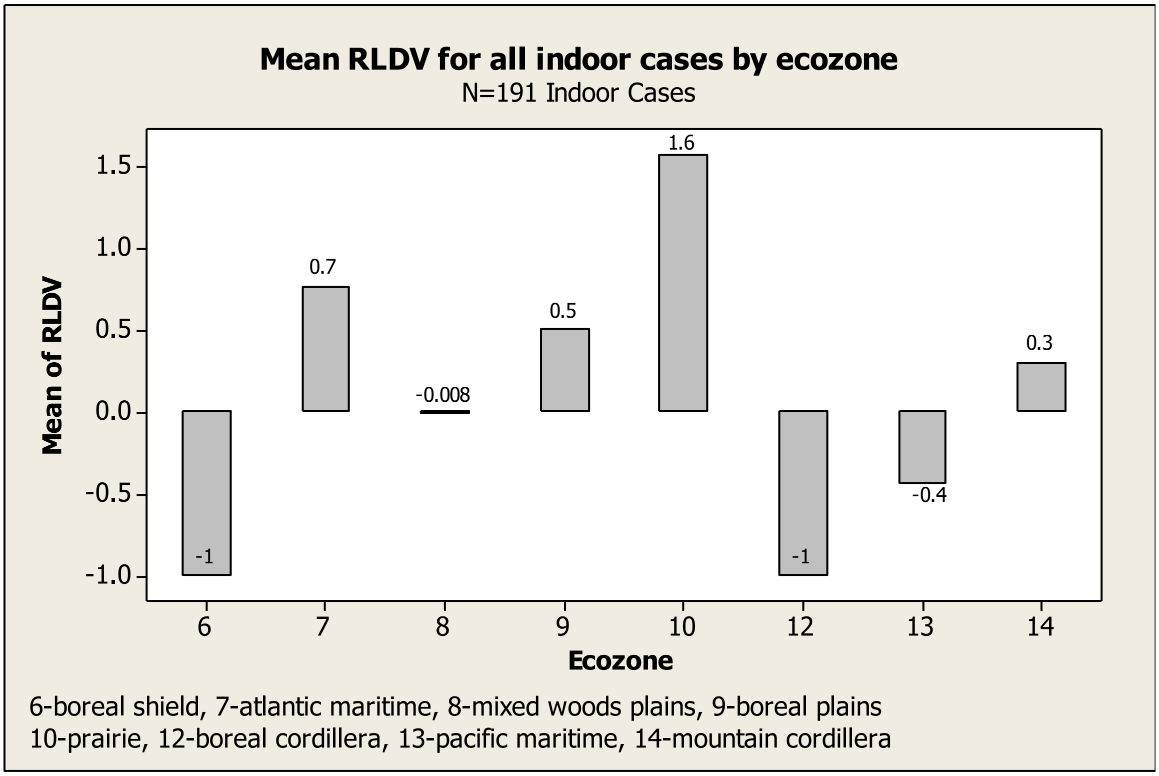


Figure 4.114. The mean RLDV for the indoor cases by ecozone. The ecozones with the largest sample sizes are 8 and 13. The results for these two ecozones are relatively similar with a mean RLDV slightly below the norm. The ecozones with mean positive RLDVs are the Atlantic maritime, Boreal plains, Prairie and mountain cordillera. Ecozone 6 – boreal shield has only one case.

The RLDV was used in an attempt to indentify variability in decomposition between the ecozones. The mean RLDV for each of the ecozones was calculated for the indoor and outdoor datasets (Figures 4.114 and 115). The results are provided as a positive or negative column above or below the horizontal zero on the diagrams. Due to sample sizes, only the cases from the outdoor and indoor scene types have been used for these calculations. The results for the inside and outside scenes by ecozone are not similar, which suggests that the ecozone is not the only factor contributing to the variability. Only the results for ecozone 14 (Mountain Cordillera) are positive for both inside and outside environments. Ecozones 6 (Boreal Shield), 12 (Boreal Cordillera) and 13 (Pacific Maritime) show a slightly negative RLDV for indoor scenes, whereas the outdoor RLDV are generally average or slightly negative.

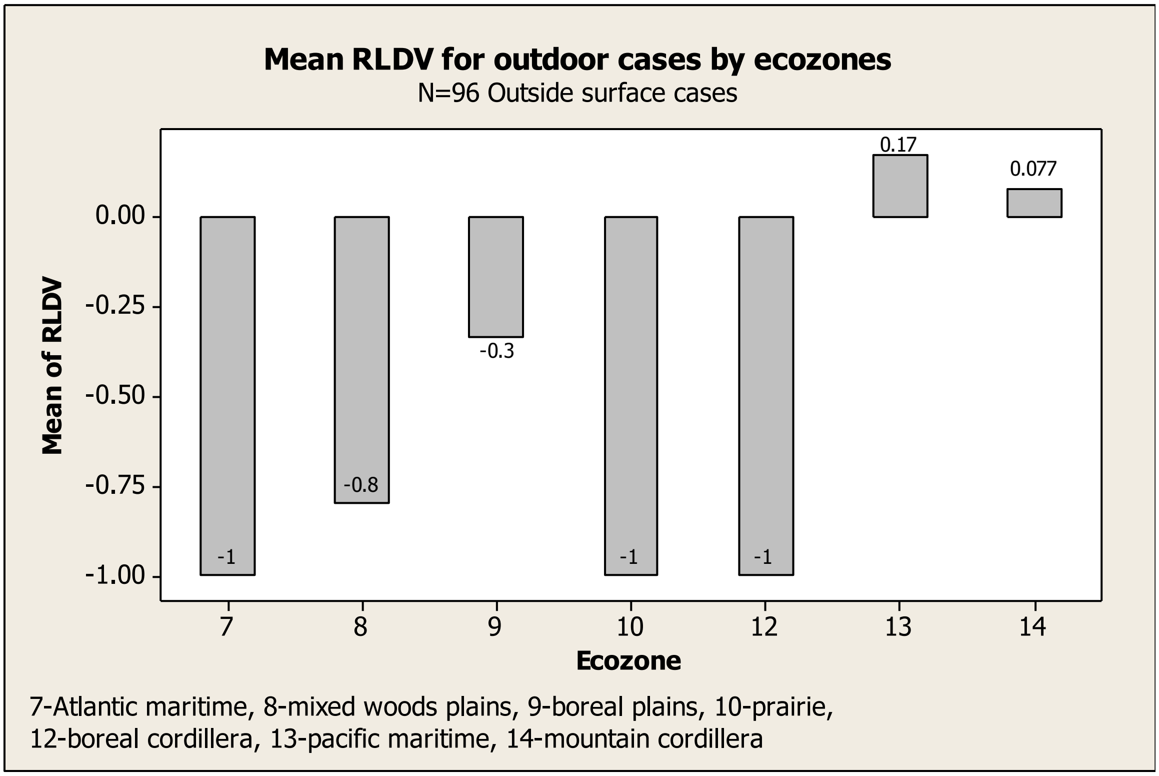


Figure 4.115. The mean RLDV for the indoor cases by ecozone. The ecozones with the largest sample sizes are 8 and 13. The results for the outdoor cases are consistently negative compared to the indoor mean RLDV calculations. Only ecozones 13 and 14 are slightly above the norm.

A negative average RLDV implies that it takes less temperature, or a lower than average ADD score for that case to achieve a specific stage of decomposition. Negative scores imply a faster rate and positive score a slower rate. There are considerable differences between the results for the indoor and outdoor scenes by ecozone. There does not appear to be any commonality in mean RLDV between the indoor and outdoor scene based on ecozone alone.

The distribution of the RLDV as it relates to decomposition did now show a geographically specific pattern. When the distribution of the RLDV was conducted looking at the distribution of positive or negative values as it relates to the variables of age, sex, body size, type of trauma, alcohol or drug use, it also failed to identify geospatial patterns.

4.4.2. ***Variability in the PMI and ADD Score Progression of Decompostion by Geographic Region***

A comparison of mean ADD and PMI scores was conducted between the two main ecozones in the Canadian dataset: the MixedWood Plain (ecozone 8) and the Pacific Maritime (ecozone 13) for both indoor and outdoor scene types (Figure 4-116 & 117). When a comparison was made using the mean PMI days between the two ecozones, ecozone 8 demonstrated a consistently faster rate of decomposition for almost all represented stages compared to ecozone 13 (Figure 4.116). A comparison of the mean ADD scores between the two ecozones did not result in a pattern of one ecozone being faster or slower than the other based on temperature (Figure 4.117). For ecozone 13, the ADD scores were lower (slower) during autolysis (stages 0, 1, 2), but variable for stage 5 for the indoor and outdoor scenes.

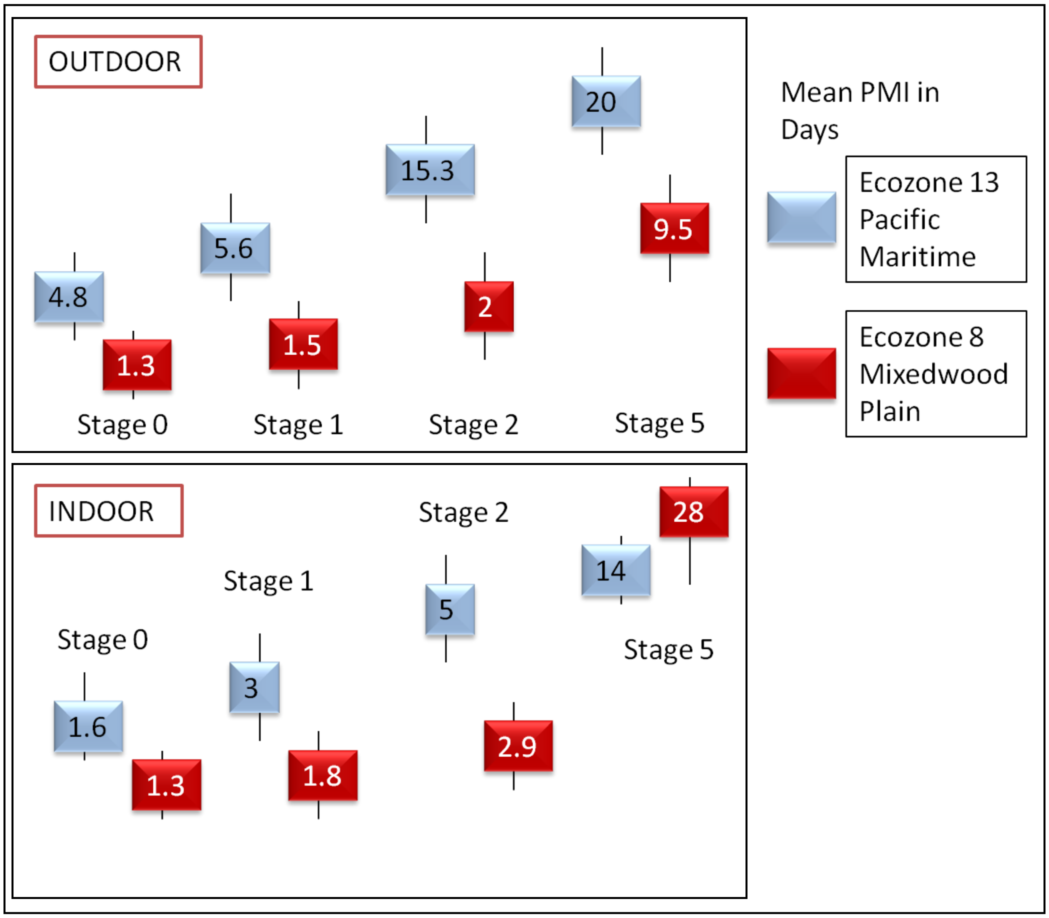


***Figure 4.116.** The comparison of the mean PMI days for stages 0, 1, 2 and 5 for the outdoor and indoor scene for two of the main ecozones. The red squares represent the mean PMI days for that stage of decomposition of the MixedWood plain ecozone in Ontario. The blue squares represent the mean PMI days for that stage of decomposition for the Pacific Maritime ecozone in British Columbia. Decomposition in the Pacific Maritime, regardless of season is consistently slower compared to the MixedWood Plain ecozone, inside or outside.*

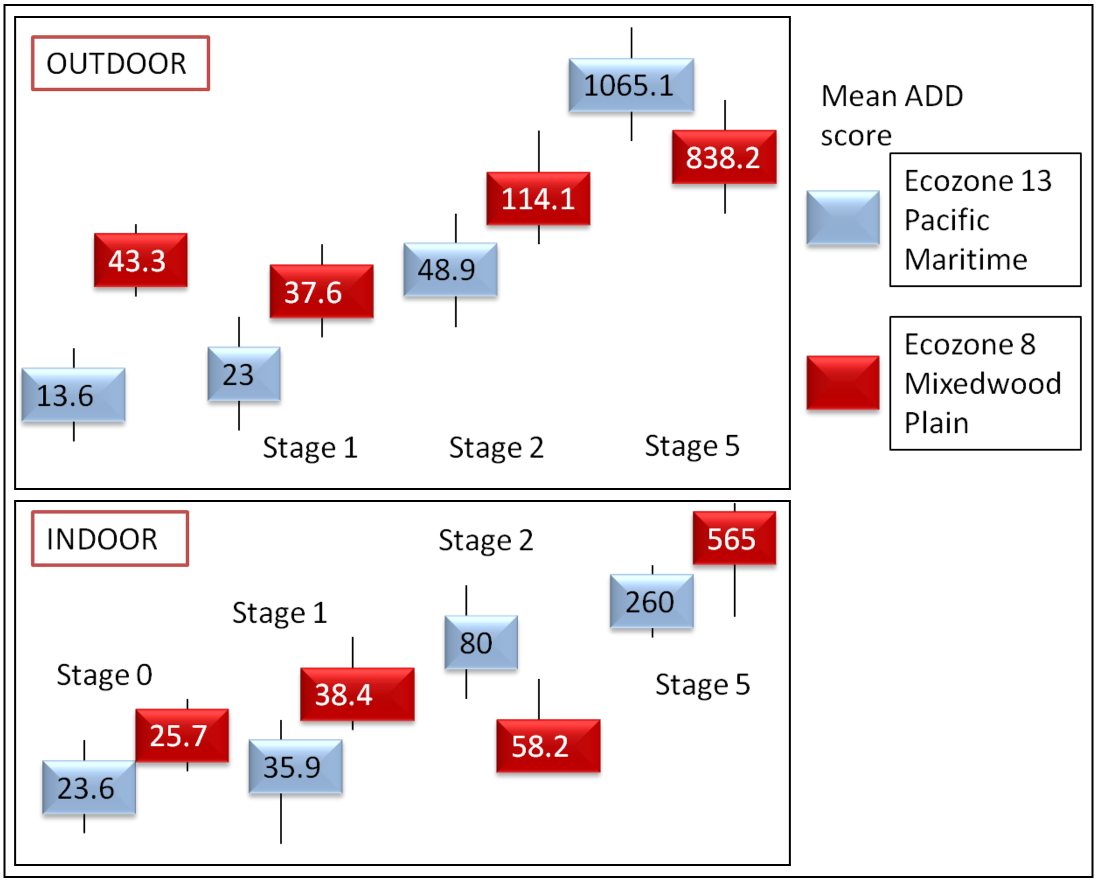


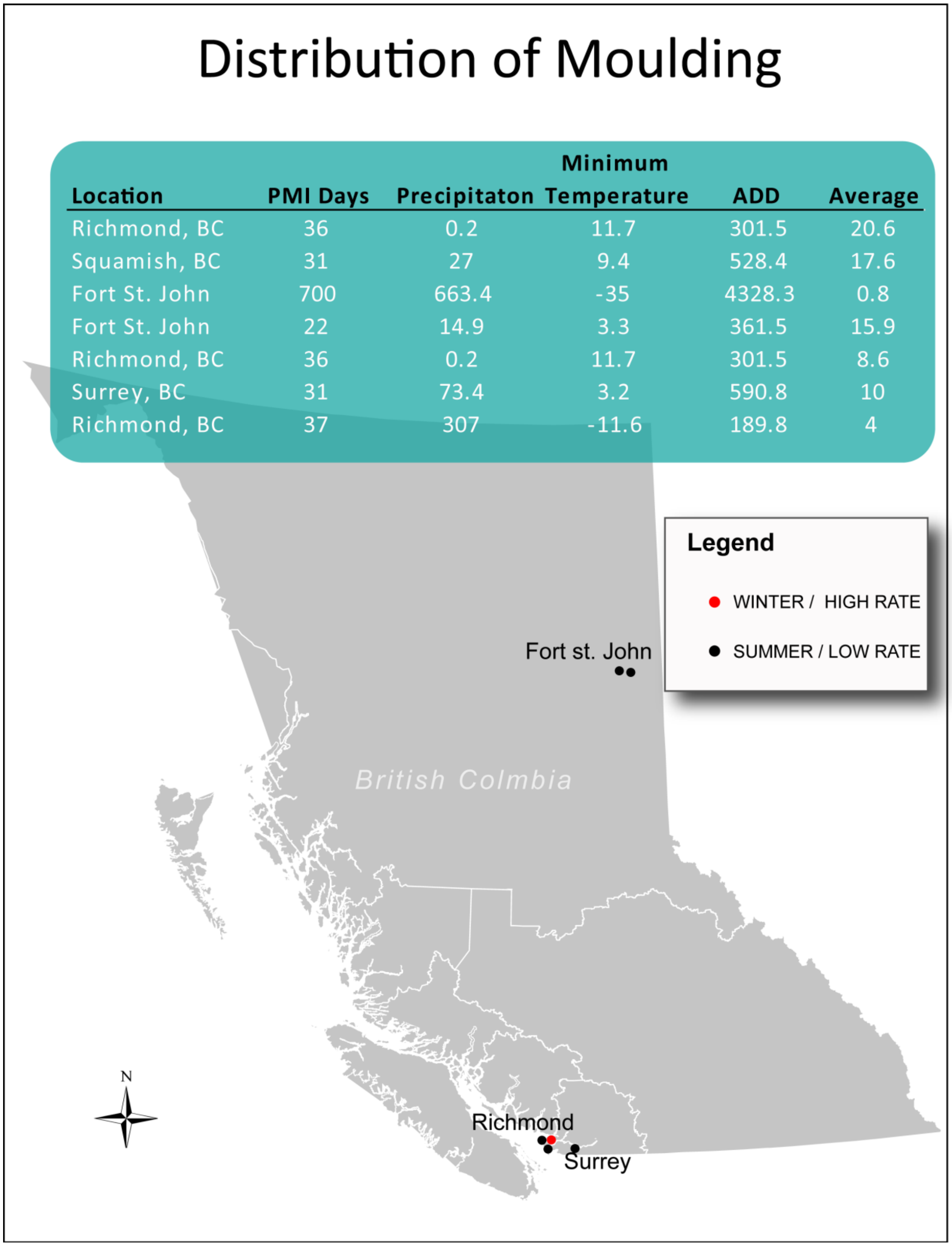
Figure 4.117. The comparison of the mean ADD scores for stages 0, 1, 2 and 5 for the outdoor and indoor scene for the two main ecozones. The red squares represent the mean ADD scores for that stage of decomposition of the MixedWood Plain ecozone in Ontario. The blue squares represent the mean ADD scores for that stage of decomposition for the Pacific Maritime ecozone in British Columbia. The differences in the mean ADD scores between the two ecozones are not as obvious as the mean PMI days. This may be the result in an issue in the methodology used to calculate the ADD score rather than a lack of regional differences.

These results demonstrate that there is quantifiable variability in the mean time and temperature it takes a body to progress along the stages of decomposition both inside and outside in the two different ecozones. A *t*-test of the differences between the mean ADD scores and PMI days for inside scenes resulted in P-value of 0.289 which is not significant. The *t*-test result for the differences in the PMI days and ADD score differences between for the outdoor scenes resulted in a P-value of 0.078 which is slightly above the level of significance.

4.4.3. ***Regional Variability in the Alternate States of Decomposition***

The external colonization of mould on a body is one of the alternate states of decomposition identified during this study. It is an alternate state as opposed to a natural stage of decomposition because its development is triggered by environmental conditions as opposed to biological processes. Moulding can occur in a high humidity context with cool or warm temperatures. The incidence of external moulding on a body has been commented on in the literature by Micozzi (1997). He proposed that mould formation was caused by cold temperatures which destroyed or retarded the enteric bacteria and resulted in the colonization of the external tissues by fungi or algae found in the immediate environment. There are very few cases of moulding in this Canadian database as is seen in Figure 4.118. All of the cases however are limited to the west coast of Canada in British Columbia. This geographic location is generally characterized by cool moist temperatures; however there is considerable climactic variability between the seasons and across the Province.

Figure 4.118. The geographical distribution of cases with moulding either inside or outside. Incidents of moulding were only found in western Canada. There are two bodies in Richmond.



Location	PMI Days	Precipitaton	Minimum Temperature	ADD	Average
Richmond, BC	36	0.2	11.7	301.5	20.6
Squamish, BC	31	27	9.4	528.4	17.6
Fort St. John	700	663.4	-35	4328.3	0.8
Fort St. John	22	14.9	3.3	361.5	15.9
Richmond, BC	36	0.2	11.7	301.5	8.6
Surrey, BC	31	73.4	3.2	590.8	10
Richmond, BC	37	307	-11.6	189.8	4

There are only 7 cases of moulding in the database; four of which from outdoor scenes, and the other three from indoor scenes. The majority of these cases involve a minimal amount of moulding in areas such as feet, hands and noses after a relatively long post mortem interval.

Figure 4.119. An example of moulding in the Pacific Maritime ecozone. PMI is 37 days and an ADD of 189.9, precipitation 307 mm.

There is a one case in the Canadian dataset which is consistent with Micozzis' (1997) proposal that mould development can be triggered after the body is exposed to cold or freezing temperatures. For bodies which have been previously frozen, he describes this modified process with the bodies decomposing from the "outside in" versus the "inside out". There is a case in the Canadian dataset where a body was exposed to freezing temperatures (minimal temperature -11.6 degrees Celsius) over a period of time. This body spent 37 days in a cool, moist and relatively dark environment. The photographs of the body at the scene do not show the discolouration, tissue changes or distension considered normal with the length of time even with the cold temperatures. What is visible on the photographs is the external colonization of some type of algae or mould (Figure 4.119).

The other cases with external mould growth are all limited to British Columbia. The PMI for these cases ranges from 31 to 37 days with an average of 33.75 days. The

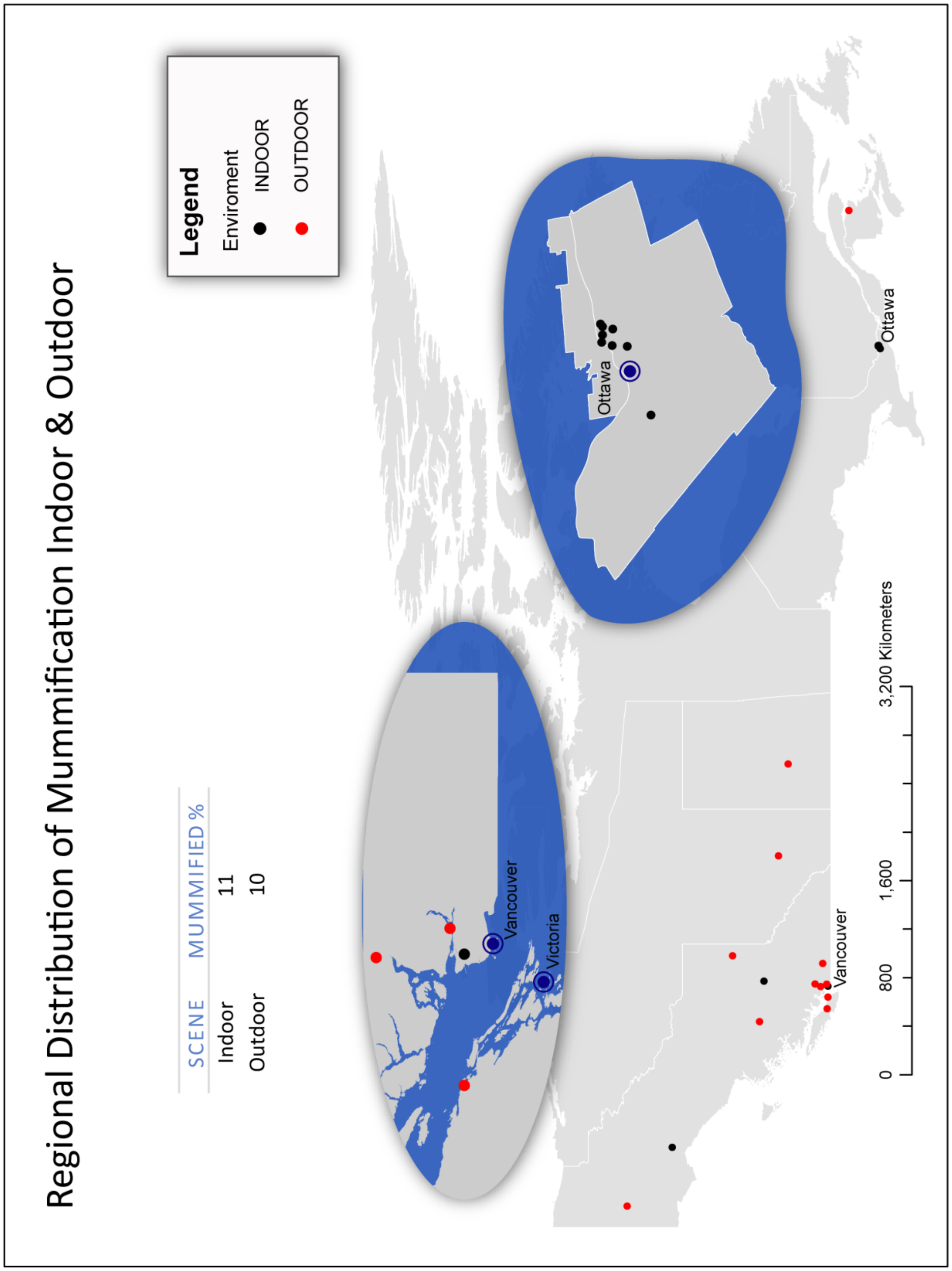
ADD scores for these cases ranges from 189.8 in November (one case) to 590.8 in August. Three of the cases decomposed during the month of August with an average ADD of 473.5 for the post mortem period. All of the bodies for these cases were located in a shaded environment, one partially submerged in water, one partially under the surface in a shallow grave and the two others in a forest environment. The level of precipitation for these cases ranges considerably, from 0.2 mm of rain to 307 mm. The average is 101.9 mm. The colour ranges for the types of fungi were from a white to yellow. The white coloured fungi can be seen in burial environments with the more advanced stages of decomposition.

It would seem therefore that the only common denominator for this type of fungal colonization is the shaded environment in British Columbia. There were multiple other cases where a body decomposed in shaded environments without the development of moulding. It would seem therefore that this particular state of decomposition may be due to cold temperatures or the geographical conditions specific to western Canada.

4.4.4. ***Mummification***

The frequency of mummification in scene types has already been discussed in previous sections. It has been established that mummification does occur on bodies in Canada however, to a much lower frequency and extent than bodies described in the United States. As mummification is triggered by arid environments, either hot or cold, the distribution of this state was examined to determine whether or not there was an ecological or geographical association. The distribution of cases with mummification is shown in Figure 4.120. The cases with mummification were located across the country from coast to coast. Mummification is likely the result of variability in humidity levels in that specific immediate environment as opposed to geographic variability.

Figure 4.120. The distribution of cases with mummification indoor and outdoor



Note: The preservation of tissues by mummification is due to the immediate environmental conditions of the body as opposed to their geographical location.

The comparison of the mean PMI days and ADD scores between the two ecozones did result in quantitative, if not statistically significant differences. In relation to the mean PMI days, the rate of decomposition in the Pacific Maritime ecozone was consistently slower, regardless of the season, inside or outside. When the geographical distribution of alternate states of decomposition was examined, it appeared that the external development of mould was limited to western Canada. There is a very small sample size of this type of alternate state of decomposition. These results therefore do not necessarily demonstrate that moulding is limited to one Province, however the data does suggest that moulding could occur in dark, moist, cool or cold environments. There is no geographical patterning of either mummification or adipocere formation either indoors or outdoors in Canada.

4.5. Part IV: PMI Estimations Based on Human Decomposition in Canada

This section will attempt to answer these two questions:

1. Can the "Universal Formula" (Vass 2011) be used to reliably predict the PMI for cases in Canada?

2. Based the biological, regional and site specific variability in decomposition discovered by this study; what is the potential to produce useful and reliable PMI estimations based on the visible state of decomposition for cases in Canada?

This section utilizes a sample of the outdoor cases to test the accuracy of two 'Universal Formulas' (Vass 2011) to estimate the PMI for bodies decomposing outside on and under the surface in Canada. The results from parts I to III of this study have been used to determine whether it is possible to produce reliable and useful PMI estimation based on the variability of decomposition in Canada.

4.5.1. *Validation of the 'Universal PMI Formulas"*

Based on his research at ARF in Knoxville, Tennessee, Vass (2011) has proposed two universal formulas for "worldwide application" (Vass 2011:34) to estimate the PMI in days for bodies decomposing on and under the surface outside. A test group of cases have been used to evaluate the accuracy of these two formulas to produce accurate PMI estimation for cases in Canada.

The two formulas are based on a number of universal rules regarding the impact of humidity or temperature on the progression of decomposition. Vass proposes that 1285 ADD represents the "empirically determined ADD value at which volatile fatty acid (VFA) liberation from soft tissue ceases" (20111:35). In other words, this is the maximum accumulated temperature at which all soft tissue has been liquefied and removed, to expose the remnant hard tissue. To test the validity of this universal rule, the cases in this study were examined to identify maximum ADD scores for stage 8 decomposition. There are 19 cases in this study with an ADD score of 1285 ADD or more. Of those 19 cases, 9 individuals are totally skeletonized (with an average of 4911 ADD). There are 10 cases in this study with active soft tissue colliquation and an ADD score in excess of 1285. Five cases were discovered in the later stages of putrefaction (average of 2337 ADD) and the other five in a state of putrefaction in combination with alternate states of decomposition such as mummification or adipocere formation (average of 3673 ADD). This maximum score of 1285 ADD may coincide with the end of soft tissue decomposition for bodies decomposing in Knoxville Tennessee; however this universal rule cannot be applied to cases in Canada.

To test the accuracy of the formula to estimate the PMI for bodies decomposing on the surface, 10 cases were randomly selected from the outdoor dataset. Following the recommendations of Vass (2011) for the use of Formula I, only cases above ground on the surface; more than 1 day PMI; intact without scavenging; exposed to only positive temperatures (no minimum temperature less than zero) and with no adipocere formation were selected. The decomposition scores for the cases were converted into a percentage by multiplying them by 12.5. No cases with a '0' decomposition score were used. The following is the formula (I) as provided by Vass (2011) for above ground (aerobic) human decomposition to estimate the PMI in days:

$$PMI\ Aerobic\ = \frac{1285\ x\ (\frac{decomposition}{100})}{0.0103\ x\ temperature\ x\ humidity}$$

The average humidity and temperatures were calculated from the online '*Canadian Climate Data and Information Archive'.* The values of 1285 represent the "empirically determined ADD value" (Vass 2011:35) at which soft tissue decomposition ceases. The 0.0103 represents the "empirically determined measure of the effect of moisture on decomposition rates" (*Ibid*). Table 4.34 provides the results of the calculation of the PMI estimations using this formula compared to the known PMI.

Table 4.34. PMI calculations using the Universal Formula I (Vass 2011)

Case	Decomp score %*	Average temp	Average humidity	Actual PMI	PMI using formula I**	Error in days And ratio diff.
1 (82)	25	13.3	66	3	36	33 (x 12)
2 (83)	25	6.5	82	2	59	57 (x 29.5)
3 (53)	12.5	4.4	85	5	43	38 (x 8.6)
4 (86)	37.5	17.9	55	2	48	46 (x 24)
5 (88)	50	16.7	85	17	44	27 (x 2.6)
6 (124)	87.5	5.6	58	25	336	311 (x 13.4)
7 (111)	87.5	15.6	84	68	83	15 (x 1.2)
8 (96)	62.5	16.3	82	9	58	49 (x 6.4)
9 (102)	75	14.5	83	31	78	47 (x 2.5)
10 (85)	37.5	15.4	83	11	37	26 (x 3.4)

Note: * the decomposition score from 0 to 8 has been multiplied by 12.5 to equate to the 0 to 100% scale used by Vass (2011). The average temperature and humidity have been calculated for the day of discovery. The case numbers in brackets relate to the specific cases from the outdoor dataset. '**' Represents Formula I for bodies above the surface by Vass (2011). The ratio difference (diff.) is the calculated ratio of difference between the known PMI and formula I PMI calculation.

The results of the comparison demonstrate that the PMI estimations calculated using formula I are substantially overestimated compared to the known PMI. There is no constant error rate which may have suggested a correction factor for Canadian cases. For these 10 cases the PMI estimation using Formula I were in the range of 1.2 times to 30 times more than the actual PMI.

Table 4.34 demonstrated that the Formula I calculated an erroneous PMI estimate at a minimum of 15 days to a maximum of 311 days over the actual PMI. In relation to the other Universal Formula (II) provided by Vass (2011) to calculate the PMI estimate for buried bodies, he provided a constant ratio of 4.6 which "represents a slowdown in the rate of decomposition [in burials] due to lack of oxygen"(Vass 2011:37). The formula requires the soil moisture at the site on the day the corpse was discovered as well as the temperature of the soil on that day. These values were unavailable for the cases in this study, and as such this formula cannot be validated using the 22 burial cases in this study. However the proposed constant value of 4.6 as the ratio for the decrease in the rate of decomposition for buried versus surface bodies has been examined using the results of this study.

Table 4.35. Ratio differences for the rate of decomposition of surface compared to buried bodies in the dataset.

Stage of Decomposition	Ratio difference for PMI in days	Ratio difference for ADD score	Relation of surface to buried bodies
0	**3**	**6.7**	**Buried faster than surface**
1	**1.3**	**2**	**Buried faster than surface**
3	0.08	9.25	Surface faster than buried
5	9.6	89	Surface faster than buried
6	6.4	163	Surface faster than buried
7	**1.9**	**1.5**	**Buried faster than surface**

Note: This information has been summarized from Table 4.4. The ratio difference is the number of times decomposition is faster or slower from the surface compared to the buried bodies for that stage of decomposition. The results are provided in PMI days and ADD scores. N=22 for buried cases & N=96 for surface cases. Not all stages were represented by the 22 buried cases.

Table 4.35 provides the summarized data for the ratio difference between buried and surface bodies taken from Table 4.4. Three of the 6 stages represented by the buried dataset demonstrated a faster rate of decomposition for decomposition in a burial context compared to decomposition outside on the surface. The stages of decomposition show a slower rate of decomposition for putrefaction for the buried cases. The average PMI ratio for putrefaction is 5.36 times slower than decomposition on the surface, in relation to the ADD score however the average ratio difference is 87 times slower than decomposition on the surface. The constant value of 4.6 for the ratio difference in the decrease in the rate of decomposition for buried bodies cannot be validated by this study. With the failure to validate this constant for Formula II, it is predicted that this formula would be unable to accurately estimate the PMI for decomposing buried bodies in Canada.

4.5.2. *PMI Estimations Based on the Canadian Dataset*

This section involves a secondary analysis of data from part I to III to evaluate the feasibility of PMI estimations based on the Canadian dataset.

Part 1 – Variability in Baseline Decomposition in Canada

Table 4.36 includes confidence intervals which were associated to the mean PMI and ADD scores calculated for the interval plots for each stage of decomposition for each scene types. Positive and negative scores provided for the 95% confidence intervals have been added to provide one positive cumulative number. Due to sample sizes, only the outdoor and indoor datasets have been used to evaluate the inherent variability in the time and temperature a body takes to decompose. The intent of this analysis is to determine whether the error rates increase in an exponential fashion which may suggest an inherent predictability in the progression of decomposition.

Table 4.36. Comparison of total confidence intervals of ADD and PMI scores for each stage of decomposition by scene type.

Decomp stage	Outdoor PMI	Outdoor ADD	Indoor PMI	Indoor ADD	Burial PMI	Burial ADD	Water PMI	Water ADD
0	3.1	17.6	1.7	11.5	50.8	378.2	5.0	137.2
1	5.1	91.5	0.5	12.1	2.9	63.8	24.4	85.8
2	37.4	160.1	2.5	46.7	0.0	0.0	34.2	257.8
3	178.0	514.6	7.1	133.1	336.0	3365.3	152.8	1302.0
4	0.0	0.0	18.7	379.3	248.8	2698.9	124.9	324.8
5	30.4	164.7	25.6	513.7	344.8	2382.9	0.0	0.0
6	290.1	1412.4	0.0	0.0	546.4	3919.9	16664.6	39033.0

The confidence interval ranges provided in Table 4.36 provide a measure of the reliability (95% confidence interval) of the calculated mean PMI and ADD scores for each stage of decomposition in all of the scene types. The only scene type which provided a reasonably small confidence error is the PMI in days for the indoor dataset. The confidence intervals increased with the progression of decomposition.

The data for the indoor and outdoor PMI confidence intervals were examined using the trend analysis with forecasts to determine if there was predictability in the increase of the error with the progression of decomposition. The outdoor PMI confidence errors were initially modeled using a linear trend. The results produced large numbers for the accuracy measures (MAPE: 307.45, MAD: 58.52 and MSD: 4982.69). The MAD expressed the accuracy of the linear trend model in days; which in this case is 59 days. The data was examined using an exponential growth model with slightly better results (Figure 4.121). With such a large error rate in the model, it was determined that a forecast of the data for the latest stages of decomposition would not to be useful.

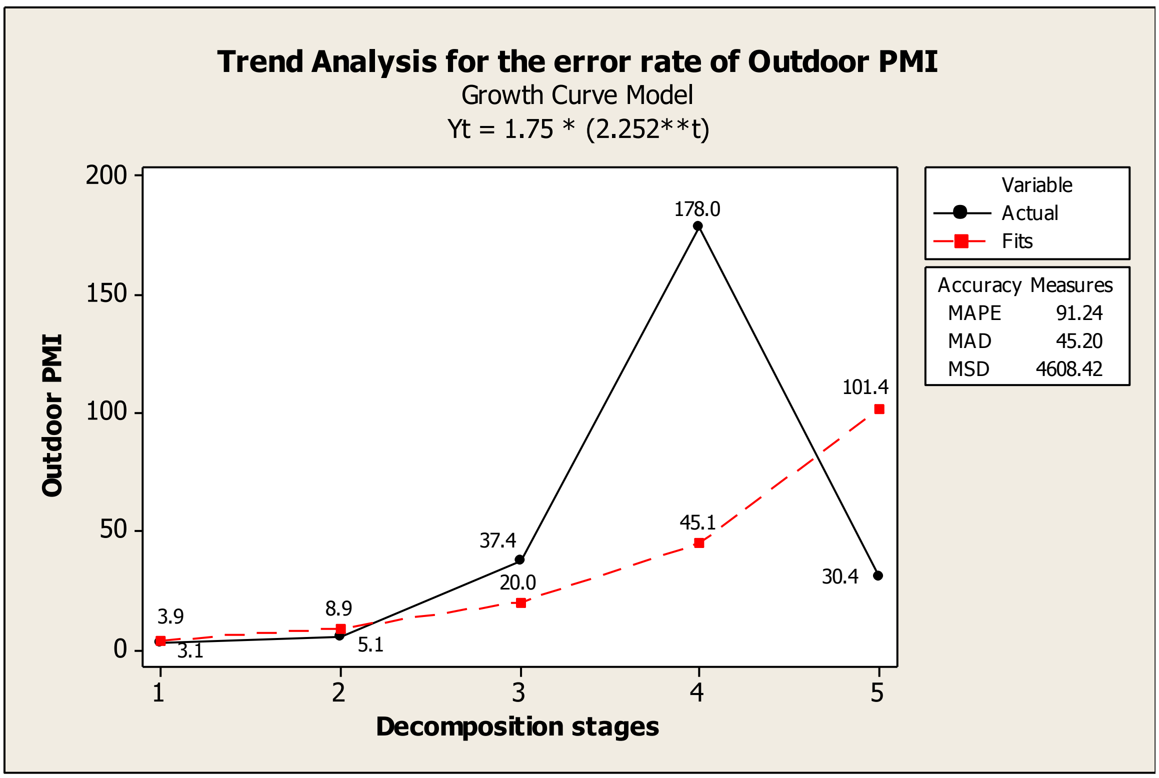


***Figure 4.121.** The exponential growth model for the confidence intervals for outdoor PMI. The resulting error rate for the model is 45 days (MAD). It is of limited use to produce a model with forecasting with an error rate of 45 days. The confidence intervals do not increase with each successive stage of decomposition.*

A trend analysis was conducted using confidence intervals from the indoor dataset. The linear model was initially used which resulted in at Yt= -8.52 = 5.11*t and associated accuracy measures of: MAPE:133.553; MAD:3.430 and MSD :14.020 (graph not shown). It was determined that the exponential growth model was a better fit for the indoor PMI data (Figure 4.122).

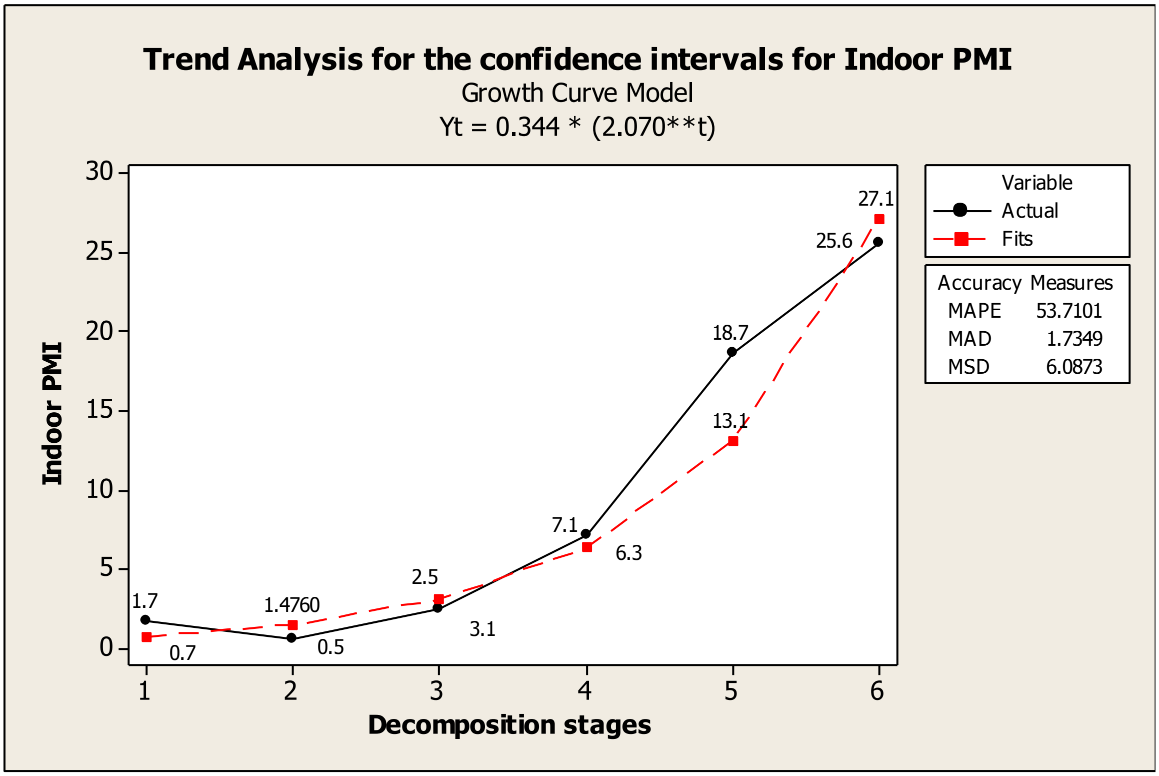


Figure 4.122. The growth curve models the exponential growth of the confidence intervals calculated for the mean PMI days for the indoor dataset. The accuracy measures demonstrate that this model has a good fit with an associated low error rate of 1.7 days.

The PMI confidence intervals for the indoor dataset demonstrate a good fit for the growth curve model. The mean absolute deviation (MAD) is only 1.7 days. With a low error rate, a forecast (Figure 4.123) was calculated for the last few stages of decomposition. The MAPE score for this model is relatively high at 54%, which provides the absolute error expressed as a percentage of the error. If the MAPE is 54%, on average the forecast is off by 54%.

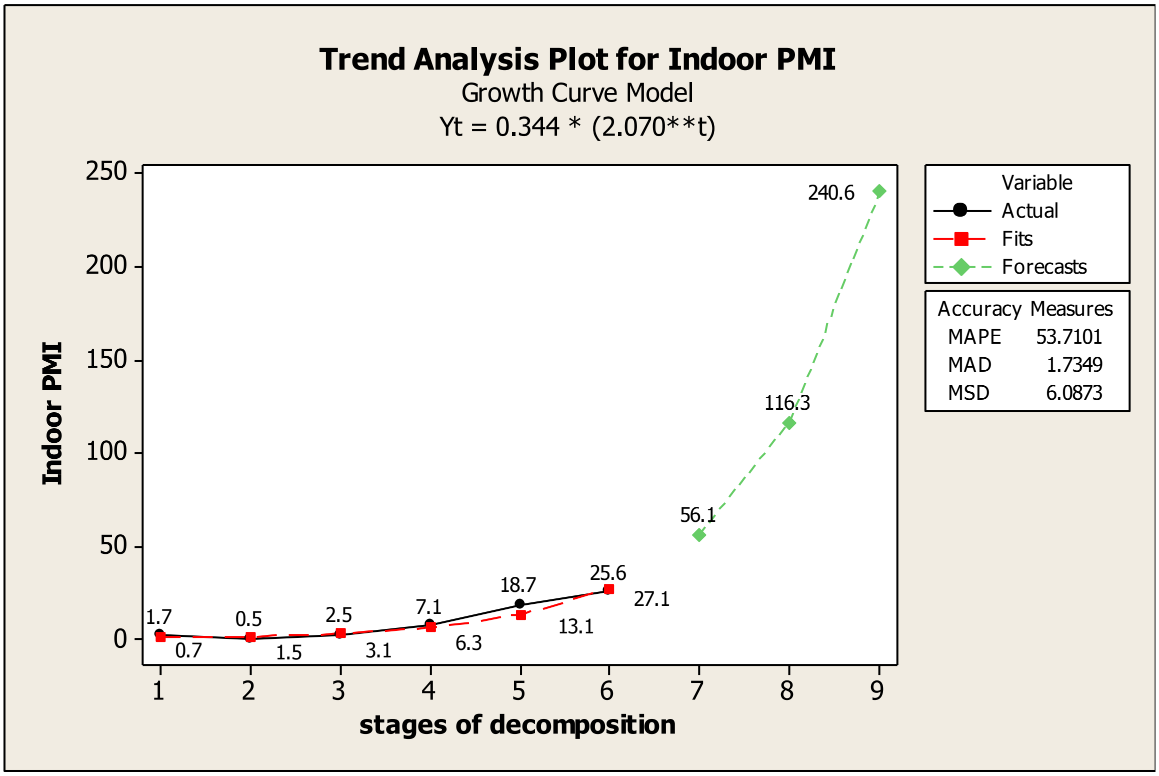


Figure 4.123. The growth curve model has been used to analyse the confidence intervals for the PMI days for the indoor dataset. The MAD provides a 1.7 mean absolute deviation. The model has been used to forecast the last three stages of decomposition if we consider the scale starts at 0 as opposed to 1.

It does appear that the confidence error does increase at a relatively predictable exponential rate with the indoor dataset. The trend analysis for both datasets demonstrates an increasing trend of error rates with the progression of decomposition. The more advanced the stage of decomposition, the larger the error rate and the smaller the potential to provide a reliable and reasonable PMI estimation.

Part II – The Variables which Affect Decomposition in Canada

The aim of the part of the study was to identify which variables had the most influence on the progression of decomposition. The data so far has demonstrated that a different array of variables may act upon decomposition in different scene contexts. Table 4.33 demonstrates that there is not one single variable, including time and temperature which has a significant impact on the variability of decomposition in all four scene types.

Table 4.37 provides the summarized results of the general and regression analysis conducted to identify variables that significantly impacted in the progression of decomposition. A total of 36 environmental, immediate and intrinsic variables identified were examined during the study. These results identify a complex of variables which contribute to the variability of decomposition in that scene type.

Table 4.37. The variables identified for each scene type which accounts for the variability in the decomposition score in the Canadian dataset

Scene type	Sample size	Variables	% of variability
Outside	96	7	83%
Inside	177	3	49.6%
Buried	22	3	50.9%
Water	27	2	53.8%
Total dataset	341	4	60.6%

Note: The data for this table has been taken from the regression analysis shown in Tables 4.28, 29, 30, 31 and 33.

The results shown in Table 4.37 show that the multivariate analysis of the outdoor dataset is the only one that resulted in the identification of a number of variables which are responsible for the majority of variability (83%) in the decomposition score. A list of the specific variables is provided in Table 4.33. The regression analysis to explain the variability in the other three contexts was less successful. The analysis identified only a few variables which accounted for around half of the variability in the decomposition score. When the total dataset is examined regardless of the scene context, only four variables are accountable for 60% of the variability in the decomposition score. The results suggest that not all of the significant variable which may be responsible for the variability of decomposition in the indoor, water and buried have been identified by the study.

Part III – The Regional Variability of Decomposition in Canada

There is an insufficient sample size of burial or water cases to examine regional variability of the data across Canada, however there are two ecozones (13, Pacific maritime and 8, MixedWood plains) with sufficient sample size to examine differences between the outdoor and indoor dataset.

Table 4.33 lists the variables which have a significant influence on decomposition in all four contexts. For the indoor context, the ADD score was determined to be more significant compared to the PMI in days. The analysis was been provided for both the ADD score and PMI for the inside dataset to demonstrate the quantified differences between the two ecozones.

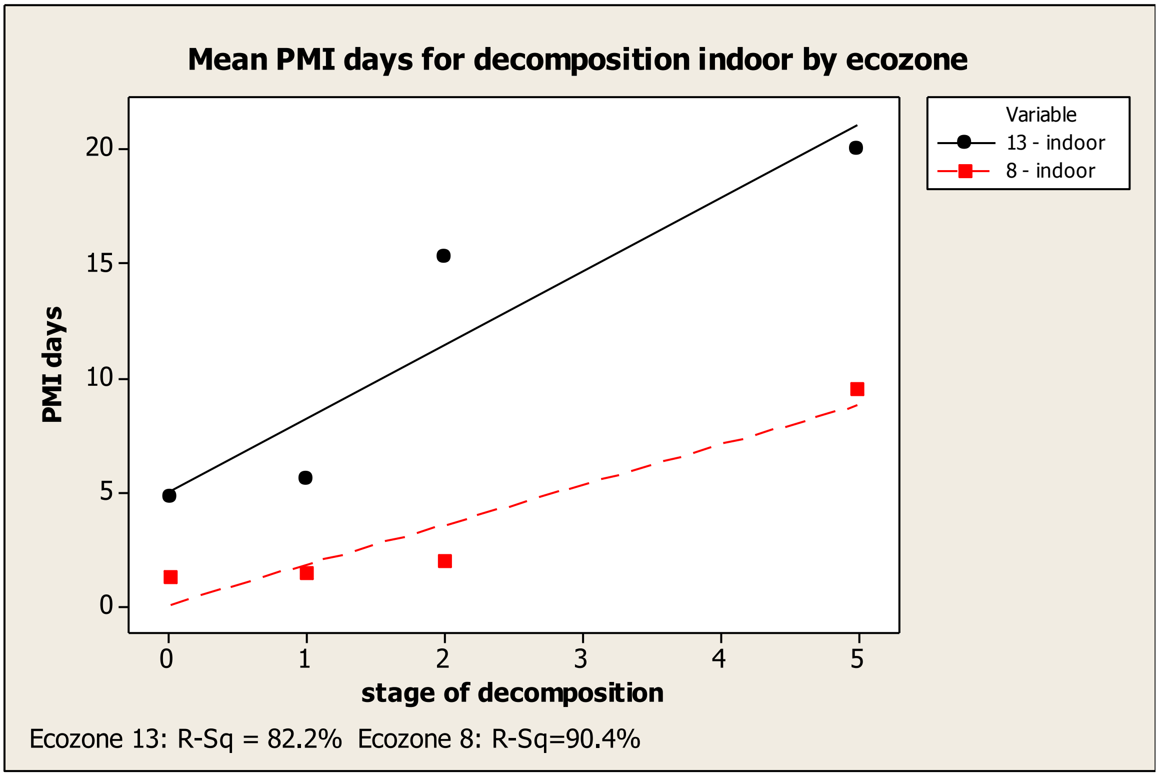


Figure 4.124. The two regression lines for the PMI days for each stage of decomposition 0, 1, 2 & 5 for the two ecozones for the indoor dataset. The line slopes are separated and different from each other. The ecozone 8 results show higher correlation between the PMI days and the stage of decomposition at 90% compared to 82 % with ecozone 13.

It has been demonstrated in Table 4.33 that the PMI in days has a more significant influence on decomposition outside. Figure 4.124 is the regression analysis of the correlation between the stage of decomposition and the PMI in days for outdoor decomposition between the two ecozones. The two slopes on Figure 4.124 are different which confirms that regardless of seasonality, there is a quantifiable difference in the progression of decomposition between ecozones in Canada.

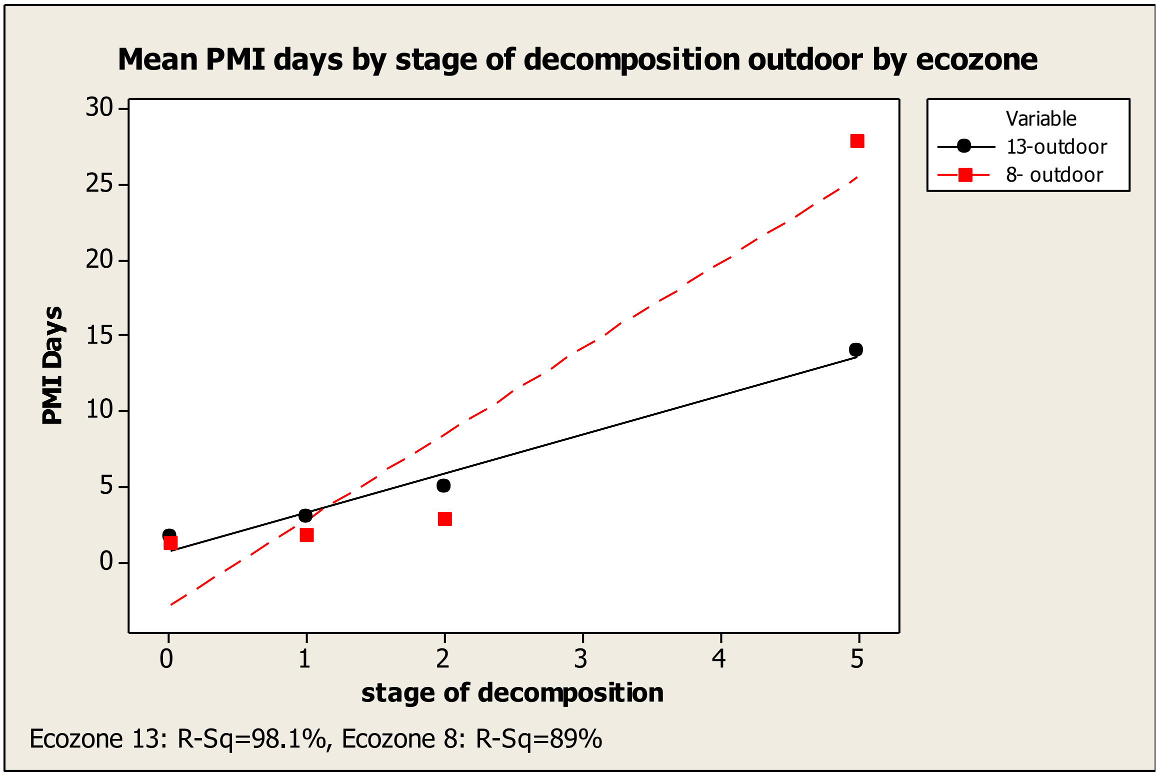


Figure 4.125. The two slopes calculated by regression analysis for the correlation between the mean PMI days for stages 0, 1, 2 & 5 for decomposition outdoor. The regression slopes are different, but overlapping.

Decomposition appears to be similar for both ecozones in the initial stages of decomposition outdoors (Figure 4.125), however the differences increase with the progression of decomposition. Ecozone 8 appears to have a faster initial progression of decomposition for stages 0, 1 and 2 compared to Ecozone 13. There is a large deviation in the mean ADD and PMI scores for stage 5 for both PMI and ADD scores. There are quantifiable differences in the progression of autolysis and putrefaction between these two ecozones.

5. Discussion

The discussion of the results is presented in this chapter and is divided into four main parts as reflected by the methods chapters:

1. The baseline progression of decomposition in the four scene types in Canada. The presence and extent of the alternate states of decomposition in these four scene types.
2. The identification of variables which impact the progression of decomposition in the four scene types.
3. The geographical variability of decomposition and alternate states of decomposition in Canada.
4. An evaluation the 'Universal formulas' (Vass 2011) to estimate PMIs and the potential for PMI estimation within the Canadian dataset.

5.1. Part 1: The Normal Progression of Human Decomposition in Canada by Scene Type

The progression of baseline decomposition has been expressed in either the passage of time (PMI in days) or temperature (ADD score) for bodies deposited in four different scene types: outdoor on the surface, outdoor buried, indoor and in water. The occurrence and frequency of alternate states of decomposition such as mummification, adipocere formation or moulding has also been provided by scene type. The results demonstrate increasing variability in the mean time or temperatures associated to each progressive stage of decomposition. There are quantitative differences in the progression of decomposition (both PMI days and ADD score) between scene types. There are also distinctive visible differences in decomposition during the later stages of decomposition due the scene context.

5.1.1. ***Baseline Decomposition Outdoors on the Surface***

A total of 121 cases in the outdoor dataset were used for this study. Of these 121 cases, 96 cases with 1 year PMI or less were used in the analysis. The PMI of 1 year or less was used to lessen the impact of large PMI or ADD scores on the averaging (mean) calculations. The majority of the cases were discovered at stages 0 – 1 decomposition (Figure 4.1). The outside cases represent a range of contexts, the most common being the wooded environment (Figure 4.2). Outside surface decomposition maintained a relatively fresh state with no visible signs of decomposition for up to 4 days on average (Figure 4.4). The onset of tissue change (skin slippage, hair loss) generally occurred at around 10 days and putrefaction started at approximately 9 days after death. The length of time needed for the onset of skeletonization (stage 6) was 109 days. More than half the bone was exposed on a body outside at around 137 days and there were no cases in this dataset with total skeletonization under one year PMI. The mean PMI was calculated with an associated confidence interval (error rate) for each stage of decomposition (Figure 4.4). The mean ADD scores were calculated for each stage of decomposition with an associated confidence interval (Figure 4.5). For both the ADD score and PMI mean scores, the confidence intervals increased with each successive stage of decomposition. The variability of time or temperature to achieve a specific stage of decomposition increased with the progression of the body from autolysis to putrefaction and skeletonization.

These results demonstrated an exponential growth in the confidence intervals associated to both time and temperature in the progression of decomposition. There is an abrupt increase in variability at stage 5 decomposition for the outdoor set (Figure 4.5). The error rates associated to the mean PMI in days or ADD scores calculated for each stage of decomposition also increased exponentially with each successive stage of decomposition. Bodies discovered on the surface outside between three months and 1 year PMI exhibit similar blackened and desiccated remnant tissue attached to exposed bone (Figure 4.9). This visible state of decomposition can be used to identify the primary scene (outside on the surface) if the body has been relocated. The summary table for the progression of decomposition in PMI days demonstrated a large time delay in the progression of the body from putrefaction to skeletonization (Figure.10), which suggests a body can stabilize and linger between stages 5 and 6 for a considerable period of time. Of the four scene types the outdoor dataset has the second fastest rate of decomposition in PMI days, with indoor decomposition the fastest, buried bodies the third slowest and decomposition in water the slowest (Table 4.11).

Mummification was the most prevalent type of alternate state of decomposition found at outdoor scene types on the surface. The onset of mummification was recorded on the extremities at 58 days in the winter. Surprisingly, mummification was recorded on average later in the extremities during the summer at 75 days (Figure 4.10). The faster onset of mummification outdoors in the winter could be attributed to lower humidity rates in the winter, as the precipitation for both summer and winter cases with outdoor mummification are almost equal (Table 4.1). The extent of mummification did increase over time with a small extent recorded around 19 days, a moderate amount around 49 days and more than 50% of the tissue around 91 days (Figure 4.11). Instances of moulding on a dry substrate was recorded in the outdoor surface scene type, however adipocere formation was not. The later stages of decomposition were visually characterized by blackened and desiccated remnant tissues associated with bone exposure (Figure 4.12). This visible state of end stage decomposition was generally only associated with bodies recovered from an outside context on the surface.

There is currently only one Canadian retrospective study which included human decomposition outdoors (Komar 1989). Of the 20 cases that were examined during his study, only two of cases retained soft tissue. The other cases were fully skeletonized over an extended period of time. In Canada, animal proxy experiments dealing with decomposition outside have been focused on forensic entomology research (Hobischak & Anderson 1999 & 2002; Anderson and Hobischak 2004; Pakosh & Rogers 2009; Christensen & Meyers 2010 and Petrick et al. 2004). One experimental archaeological study examined the processes of decomposition in reconstructed prehistoric stone burial cairns in Edmonton, Alberta (Wietzel 2005). Therefore, as previously discussed in the literature review, the sum total of our knowledge relating to outdoor surface decomposition in Canada consists of two human cases. Due to damage caused by the extensive scavenging of large carnivores, the description of decomposition for those two cases is limited.

The largest set of cases used in any retrospective study was published by Galloway et al. (1989). This study was conducted to examine decomposition in the arid environment of Arizona. The Arizona study included 96 cases from an outside surface context and demonstrated a much more rapid rate of decomposition with mummification as part of the baseline decomposition (Galloway et al., 1989). In Arizona, only the bodies deposited in the winter months retained a fresh appearance for the first day. Lividity was recorded for all bodies at 2 days PMI. The onset of putrefaction (early decomposition) was recorded as early as one day after death and as late as 5 days. Bodies were recorded in a state of post-bloat by day 7 of the PMI. Galloway et al. (1989) described the last stage of putrefaction as the darkening of the external surface and the eventual rupture of this surface due to abdominal gasses. This rupture could occur as soon as 3 days but was more commonly seen after 8 days. Advanced decomposition was recorded from the 4^{th} to the 10^{th} day which was followed in most cases by desiccation or mummification of the external tissues. The end stage of decomposition of the soft tissues was the formation a mummified shell over the skeleton. The entire process of fresh state to mummified shell could occur in the arid environment during a period of 10 days to one month.

The progression and rate of decomposition recorded for cases in Arizona is very different from the decomposition documented for Canadian cases. The rate of decomposition is much faster in Arizona, with bodies arriving at each stage of decomposition earlier compared to the Canadian cases. The arid environment triggered an early onset and cumulative development of mummified tissue during almost every stage of decomposition in Arizona. Only a limited extent of mummification occurred to exposed extremities during the initial stages of decomposition for the Canadian cases. The visible end stages of tissue decomposition was very different between the two regions; with a mummified shell of tissue forming over the remains in Arizona, while only a small amount of blackened, desiccated tissue adhered to exposed bone in the Canadian cases.

There have been a number of other regionally based retrospective studies conducted for outdoor decomposition in the United States. Rhine and Dawson (1989) examined 35 cases from the southwestern United States and Sorg et al. (1998) examined 34 cases from Northeast United States. Unfortunately the emphasis of these studies was on the deterioration of bone as opposed to soft tissue over a very long period of time. Little to no information was provided relating to the progression of soft tissue decomposition. The study by Rhine and Dawson (1989) did state that total skeletonization was recorded in the Southwest region within a period of 21 days (1998). Mummification occurred more frequently in a more temperate environment at higher altitudes compared to a more arid and hot environment in the Southwestern United States (Rhine and Dawson 1998). The onset of mummification in these two studies does not appear to be as dependant on humidity levels as was seen with the Canadian cases.

Megyesi et al. (2005) examined 57 cases from outdoor scenes; however the purpose of the study was not necessarily to describe the progression of decomposition, rather, to evaluate the contribution of the ADD score to the progression of decomposition. No temperature or time ranges were provided for the stages of decomposition in this study which included cases from all over the United States. Another retrospective case study was conducted by Komar (2003) in New Mexico, in the United States. This study presented the frequency of sex, age, type of trauma, scavenging and PMIs for the 598 individuals in the study. No attempt was made to classify the stages of decomposition and establish a baseline sequence of decomposition for the area.

There is only one retrospective study which was conducted outside the United States; in Spain. A study conducted by Prieto et al. (2004) examined 29 cases to establish a very basic sequence of decomposition in Spain. The observations of this study indicated that the progression of putrefaction in Spain could take anywhere from one week to one month on the surface. Initial skeletonization could take two months, with advanced skeletonization between 6 months to 1.5 years, and complete skeletonization more than one year on the surface. In Canada, the process of putrefaction outside is generally visible at approximately 9 days PMI and could persist until 109 days (more than 3 months). There is a considerable degree of variability in the duration of the putrefaction stage for cases in Canada. The beginning of skeletonization had been recorded after more than 3 months on the surface regardless of the season. Considering the ecological and environmental differences between Spain and Canada, it would appear that the rate of decomposition for putrefaction and skeletonization in these two countries are slow and unpredictable compared to decomposition in the southern United States (Galloway 1989, Rhine and Dawson 1998).

The differences in the rate and visible progression of decomposition may be due not only to temperature differentials, but also humidity. The progression of decomposition in arid environments appears to be dominated by mummification. In both the Arizona study and this study, the end stage of soft tissue appears to be remnant desiccated mummified tissue. In the arid environment, the mummification of this post putrefaction tissue has stabilized to such an extent to promote more preservation compared to the Canadian cases. With the Canadian cases, humidity facilitated the liquefaction of tissue to expose more of the skeletal remains. The time it took to achieve end stage decomposition outside in Canada was approximately three times longer than the Arizona cases. The potential to accurately predict the PMI based on the visible stage of decomposition decreases with each increasing stage of decomposition. The differences in the rate and visible quality of decomposition between geographical and ecological regions suggested that universal classification systems and schedules of decomposition cannot be used to describe human decomposition.

5.1.2. ***Baseline Decomposition for Buried Bodies***

Only 22 cases (6%) in this dataset included cases with outdoor burials. The majority of the bodies were located in shallow graves (17) and the rest (5) in deeper graves. The mean ADD score and PMI days was calculated for each stage of decomposition (Figures 4.14 and 15) for the buried subset. The progression in time for the buried cases shows the onset of increased variability at stage 5, similar to the outdoor surface cases (Figure 4.13). The time progression of decomposition in a burial is similar to decomposition on the surface up to stage 5. From stage 5 onward, the variability for the time spent in each stage of decomposition is extremely variable (Figure 4.19). From stages 6 to 8, the buried cases took one and a half times longer to decompose than the surface cases (Table 4.2). Decomposition in the burial environment is only faster than decomposition in water (Figure 4.11).

The relative rate of decomposition was not constant during the entire progresses of buried decomposition The rate of decomposition for the early stages (stages 0 and 1) was slightly faster for the buried cases, at a ratio of 1.3 to 3 times, compared to the cases on the surface (Table 4.3). The time it took the buried cases to reach stage 3, the onset of putrefaction was equivalent to the time it took cases on the surface. Stage 4 was not represented in the buried set. The time range for stage 5 and 6 for burial cases demonstrated considerable variability, much like decomposition on the surface. It is within these stages that decomposition appeared to be much slower, with the rate of decomposition 6 to 9 times slower compared to those on the surface. The overall time it took cases to achieve stage 7 was only 1.2 times slower compared to the cases on the surface (Table 4.3). The cases which were deeply buried achieved stage 6 decomposition after an average of 191 days, compared to 203 days for shallowly buried cases (Table 4.5). The assumption that bodies buried at deeper depths would decompose at a slower rate was tested and not validated. For the cases buried in a shallow grave, it took on average 203 days to reach stage 6 compared to 191 days for the deeply buried cases (Table 4.4).

There are 'rules of thumb' used by forensic anthropologists to estimate the rate of decomposition for bodies on the surface compared to those underground. Fisher suggests that one week in the air equals two weeks in the water or eight weeks in the soil (1973:21). However Rhine and Dawson have stated that:

> "It is generally accepted that for a week of surface exposure of a body, approximately two weeks are required in water and three if buried to reach the same level of decomposition" (1998:155).

These two rules of thumb are based to some extent, on the early research conducted at ARF, Knoxville, Tennessee (Bass and Rodriguez 1983 and 1985). Rodriguez and Bass (1984) conducted a ground breaking experiment with six un-embalmed cadavers at ARF. They evaluated the decomposition of these six corpses buried at a variety of depths for a period of two years. Two of the corpses had been autopsied and all were placed in a variety of positions with and without clothing. The bodies were exhumed at regular intervals for evaluation. The bodies were described as progressing through stages of "tissue shrinkage" (Rodriguez and Bass 1984:843) and adipocere development with skeletonization of the extremities and head. They concluded by stating that "the decomposition of buried human cadavers occurred at a much slower rate than that of cadavers placed above the ground" (Ibid: 849). The assumption that bodies take 3 to 8 times more time to decompose under, versus on the surface, has not validated by this study. In fact the t-tests for the comparison between the ADD scores and PMI (in days) calculated for each stage of decomposition between buried and surface cases demonstrates there is no statistically significant difference (Table 4.5 and 4.6). The studies also suggested that the deeper the burial, the less oxygen available and the slower the rate of decomposition (Bass and Rodriguez 1983 and 1985). Shepherd also stated that burial would slow the rate of decomposition considerably (2003). The assumption that the rate of decomposition decreases with the increasing depth of burial was also not validated by this study.

Not all decomposition researchers agree with a deceleration of decomposition based on burial depth. Janaway (1996) suggested that the more porous and permeable the soil, which allows the free exchange of water and oxygen, the faster the rate of decomposition. There are those who believe that a shallow burial may accelerate the rate of decomposition compared to deeper internment based on the absence of bacteria (Allison and Briggs 1991). The bacterium that decomposes the body from outside in, is limited at deeper stratas due to the reduction in available oxygen and organic material.

The results of this study found that there was not only a quantitative difference in the time or temperature taken to progress along the stages of decomposition under the ground, but there were also a visible difference in the appearance of bodies exhumed during late stage decomposition. The exhumed bodies exhibited a moist dark brown discoloration. Galloway et al. (1989) observed that there was an alternate cycle to normal decomposition in buried environments. In her study the bodies did not mummify due to increased levels of moisture underground. These bodies decomposed more rapidly than those on the surface due to accelerated autolysis and putrefaction under the surface which led to either skeletonization or adipocere formation. Galloway et al. (1989) commented that bodies interned in direct contact with the soil demonstrated a very moist decomposition with skin slippage and fungal growth. She stated that adipocere was commonly seen at various stages of decomposition in buried remains.

The study by Komar (1989) included retrospective cases near Edmonton, Alberta. She stated that shallow burial resulted in rapid decomposition, while deeper burial resulted in greater tissue preservation despite a longer post mortem interval. This observation is interesting as there were only two burial cases in the study with PMI information available for only one of them. In relation to the case with the known PMI, the remains had been extensively scavenged by bears. These two cases represent the only published information pertaining to decomposition in a burial context in Canada.

An animal proxy study on decomposition was conducted, again in the Edmonton, Alberta region, involving a number of pigs placed in specially constructed stone crypts (Wietzel 2005). These crypts were constructed based on the design of archaeological stone crypts constructed during the prehistoric period in the Lake Baikal region of Siberia. The intent of the study was to conduct experimental archaeology research. The study found that pigs entombed in June reached total skeletonization in three to five weeks, while those placed in the crypt in May took longer, with a period of five weeks to three months. Due to the very specific nature of the stone crypts, the use of pigs and the fact that Galloway's (1989) arid environment classification system was used to describe the progression of decomposition, the comparison of these results to the current study may not be of value.

Adipocere Formation in Burials

Adipocere formation was rarely observed in this study. Only four (18%) of the buried cases exhibited any degree of adipocere formation. The anatomical location of the adipocere for these cases was generally limited to limbs. The earliest occurrence of adipocere on a buried body was 154 days, compared to 190 days in water (Figure 4.19). The only case in the dataset with full body adipocere formation had a PMI of over 9 years.

The development of adipocere has been reported in a study examining cemetery burials in the United States and in Canada (Manhein 1997:472). Six reported cases were located in Ontario and Quebec; only one case demonstrated any kind of adipocere formation. This case involved a double burial at a depth of 4 feet with a PMI of 122 years. Interestingly, another double coffin in Ontario buried at the same depth with a PMI of 121 years did not show any signs of adipocere development (Manhien 1997: 476-7).

The lack of adipocere development in burials appeared to differ from the normal progression of decomposition underground in Arizona and Knoxville, Tennessee. This reduced level of adipocere formation may not be the result of reduced moisture levels as precipitation levels are generally high for most cases in the study (Figure 4.60). The precipitation levels for Arizona are certainly lower than Canadian levels. The difference may be due to the higher temperatures in Arizona and Tennessee. It has been speculated that adipocere is triggered by warm, rather than cool, moist un-oxygenated environments with the presence of *Clostridium perfringens* (O'Brian & Kuehner 2007).

Forensic Soil Chemistry

Although there has been considerable research surrounding the decompositional processes of bodies in soil, the focus has been on the decompositional fluids produced by the body and recovered from the surrounding soil to develop PMI estimation methods (Vass et al., 1992, Camriol et al., 1998 and Dent et al., 2003). Other researchers have focused on the chemistry of odours emanating from a decomposing corpse buried under the ground to formulate more effect methods of locating clandestine graves (Vass et al., 2007). The impact of exhuming and re-burying experimental animal proxies has been examined to determine whether or not that disturbance influenced the overall process or rate of decomposition (Neher et al., 2003, Aslam & Simmons 2007 and Bachmann & Simmons 2010). Considerable research has also been conducted on the mechanisms and genesis of adipocere formation (Yan et al., 2000, Takatori 2001, Forbes et al., 2005 (a - c) and O'Brien & Kuehner 2007) and the impact of different soils or sub-surface ecosystems on the progression of decomposition of buried pigs (Wilson et al., 2007, Turner and Witlshire 1999). Only 6% of the cases in the Canadian dataset involved buried bodies, which indicates how rarely this occurs as a means of body disposal in Canada. Only two of those cases involved bodies buried entirely under the surface (deep burial). The amount of research effort focused on the forensic burial may be the result of the disproportionate participation of forensic archaeologists/anthropologists at burial scenes compared to indoor, outdoor or water death scenes which may have provided the impression that disposal of homicide victims by burial is more common than it actually is.

A general description of baseline grave decomposition has been provided for the cases in this study. The assumption that decomposition in graves is much slower than on the surface has not been validated by this study. For some stages of decomposition, the rate is faster for the buried bodies compared to those on the surface. It has also been demonstrated that the depth of burial does not significantly decelerate decomposition. The moist quality of buried tissues may assist crime scene investigators recognize a buried body which has been exhumed by scavengers. This recognition of an exhumed body would ensure that crime scene examiners conduct a search for the originating grave and crime scene.

5.1.3. ***Decomposition Indoors***

Sledzik (1998) held that “bodies not exposed to the elements of nature will show a slowing of the rate of decomposition” (1998:114) due to the lack of access by carrion insects, carnivores and lack of temperature and humidity ranges. This study found that bodies decomposing in an enclosed environment inside generally decomposed at a faster rate than bodies outside regardless of season or temperature (Figure 4.11). The most common type of scene for the discovery of homicide, suicide or natural death victims, is indoors. The most common stages of decomposition are stages 0 and 1 (Figure 4.22). This study included 194 cases with a post mortem interval of 1 to 421 days. Bodies inside reached the first visible stages of decomposition after 2 days. Putrefaction was reached after approximately 7 days and the end stage of putrefaction (stage 5) would linger for a considerable period of time (Figure 4.25). Like the outside and buried cases, the indoor cases demonstrated an increased variability in the mean PMI (in days) at stage 5 (Figure 4.23). This variability in the mean PMI days and ADD scores for each stage of decomposition indoors is demonstrated in the spread of the curve associated to the later stages of decomposition in Figures 4.26 and 4.27

Bodies decomposing inside reached each successive stage of decomposition 2 to 3 days earlier than the bodies decomposing outdoors (Figure 4.11). Bodies inside remained at stage 5 for a long period of time compared to the bodies outdoors. Skeletonization was not documented for cases inside, regardless of the PMI or ADD score (Figures 4.25 & 4.26). Limited bone exposure was recorded with one anomalous indoor case. This individual had been emaciated prior to death due to disease (AIDS) and bone was exposed due to mummification and skin splitting after a PMI of only 10 days (Figure 4.29). All other bodies in this dataset stabilized at stage 5 decomposition and did not progress to the stages of skeletonization. Baseline decomposition indoors was not impacted by the temperature and humidity fluctuations of the seasons likely due to the ameliorating impact of furnaces, air conditioners and humidifiers (Figure 4.35).

There have been no previous studies conducted on indoor decomposition in Canada, and very little from any other country. In Canada, all other retrospective studies have been conducted to investigate decomposition outside in water (Petrick et al 2004 and Hobischak & Anderson 1999), or outside on the surface or in burials (Komar 1998). This study has provided the first baseline progression of indoor decomposition in time and temperature. This study has demonstrated decomposition occurs more rapidly indoors than outdoors in Canada. For the Canadian cases, mummification and tissue stabilization is the prevalent state of end stage decomposition as opposed to skeletonization. The visible appearance of a body which has decomposed indoors is distinctive from the other three scene types, which would allow investigators to recognize a body which had been relocated from an indoor context.

Alternate States of Decomposition Indoors: Epidermal Bullae and Mummification

There are quantitative differences between decomposition indoors versus outdoors. This study has found that there was a qualitative difference in the visible appearance of bodies decomposing indoors. Only the bodies decomposing inside exhibited the formation of epidermal bullae during late stage decomposition (Figure 4.31). The epidermal bullae were generally associated with stage 5 decomposition (14 cases) (Table 4.7). The presence of 'dried out' epidermal bullae was indicated by the 'onion skin' patches on the soft tissue (Fig. 4.32). There were 7 cases at stage 5 decomposition indoors that did not show visible evidence of epidermal bullae, of the specific conditions of those cases, the only commonalities were the consumption of drugs and alcohol and their geographical location in Ontario (Table 4.7). It is suspected that the humidity levels in the inside environment which plays a much larger role in the development of epidermal bullae over temperature. It is proposed that with lower humidity levels indoors, the epidermis dries between 10 and 26 days (mean PMI of stages 4 and 5) during putrefaction which limits the escape of liquid through the outer layers of the skin during stage 5 decomposition. The visible appearance of the soft tissue during late stage decomposition was dark red to brown black discolouration with epidermal or dedicated bullae.

The mean PMI in days was provided for the progression of mummification indoors (Figure 4.38). After a period of one week, cases demonstrated a small amount of mummification localized to exposed extremities and facial features such as nose and ears. It took approximately 20 days for 50% or less of the soft tissue for the cases in this study to mummify. After more than a month (36 days), cases exhibited more than 50% mummification. There were no cases in this dataset with total tissue mummification.

Galloway (1989) used 58 indoor cases (31% of the dataset) in her analysis of decomposition in arid environments. The study found that skeletonization (more than half the total bone exposed) was achieved in an indoor setting during the summer in an arid environment within 7 days (Galloway et al., 1989:611). The same study also indicated that decomposition indoors was different from that outside, in that protection from the elements inside retarded the development of mummification which resulted in an accelerated rate of decomposition (*Ibid)*. The retention of moisture was what resulted in the exposure of the skeletal elements for the cases in Arizona.

The differences in the results between the Canadian dataset and the Arizona study was likely due to the temperature and humidity differentials between inside and outside in these two geographical locations. In Arizona, the outside summer temperatures would be extremely hot with low humidity compared to the cooler moister environment of the air conditioned indoor scenes. Given the lack of mummification and relative humidity; liquefaction would be more likely to occur inside versus outside. In Canada, the outside environment is generally cooler than the inside environment, either summer or winter. Humidity inside would likely be lower inside in Canada compared to outside scenes which results in mummification indoors. It is proposed that one of the most important variables in the indoor context is relative humidity. The humidity may be the cause of more extensive mummification inside compared to the outside.

5.1.4. ***Baseline Decomposition in a Water Scene***

There were 27 cases in this study recovered from the water; all with one year PMI or less. The cases in the water dataset were discovered at stages 0 to 6 decomposition (only one case at stage 5) (Figure 4.36). The mean PMI days and ADD scores have been provided for each of the stages of decomposition (Figures 4.37 & 4.38). The variability within baseline decomposition appears to commence at the onset of putrefaction (stage 3), as opposed to the end of putrefaction (stage 5), which was recorded with all other scene types (Figure 4.36). It took considerably longer for a body in water to achieve each stage of decomposition compared to bodies inside, outside or in burials. It took on average 9 days to develop the first visible signs of decomposition (stage 1) and 47 days to achieve the onset of putrefaction (Figure 4.44). This data suggested that the differences between outside and water scenes are at a maximum during putrefaction. The bodies in water decompose 3.8 times slower during putrefaction, compared to bodies outside on the surface. There however large error rates associated to these calculations due to the small sample size.

Qualitatively, there are a few visible differences for bodies recovered from water compared to the other scene types. Skin sloughing is common (Figure 4.40) and the later stages of decomposition are dominated by a reddish discolouration of the tissue (Figure 4.42) which progresses to a black discolouration if the tissue is exposed to the air (Figure 4.43). The late stage terrestrial cases also have black desiccated tissue; however this tissue is in smaller amounts adhering to exposed bone. This study has demonstrated that decomposition in water proceeds at a slower rate than any of the other scene types. The variability in the progression of baseline decomposition occurs between the transition of autolysis and putrefaction. Bodies in water can linger in a putrefactive stage for a long period of time (up to 255 days). The distinct reddish discolouration of the tissue of bodies recovered from water can help distinguish whether a body on a shoreline has been deposited there from the land or from the water.

The general assumption in forensic anthropology is that bodies decomposing in water will have a slower rate of decomposition compared to bodies exposed to the air on the surface. Petrick et al. (2004) and Rhine and Dawson (1998) stated that the ‘general rule’ is that a body will decompose twice as fast on the surface compared to the water.

Many of the human decomposition researchers agree that immersion in water will slow the progression of decomposition (Galloway et al. 1989; Shepherd 2003 and Rhine and Dawson 1989). This study did confirm that immersion in water does in fact slow the rate of decomposition; however the relative rate of deceleration is approximately four times slower for putrefaction in water compared to the surface. The relative rate of decomposition is not constant, but variable according to the stage of decomposition.

Hobischak and Anderson (1999) conducted a retrospective analysis of coroner's cases recovered from freshwater waterways in British Columbia (BC). The focus of this study was to evaluate the insect involvement of bodies in water as opposed to the progression of decomposition. Limited information was provided for the timing and progression of human decomposition in water. According to the authors, the descriptions of the level of decomposition supplied by the pathologists were vague and limited, with almost no mention of insect involvement. From a possible 30 cases, only 3 cases had entomological evidence collection. Even the authors were surprised with this low representation and suggested that there must have been insects present on more than 3% of the cases, implying that the evidence was either missed or not noted in the records (Hobischak and Anderson 1999).

The PMI estimations provided in a study by Hobischak and Anderson (1999), for human remains recovered from water were presented in approximate days, months and years. Interestingly, in a pie chart providing information regarding how these post mortem intervals were established, a large slice of the data (no numbers or frequencies) included cases where the body was not recovered. This certainly begs the question as to how the level of decomposition was evaluated without a body. Decomposition descriptors such as; washer woman skin, goose bumps, foul odour and presence of silt are discussed in relation to the bodies but not related to any biological stage of decomposition. The results of the study were that standardized terminology and distinct classification stages were needed to define the advancement of decomposition in water. Due to the inconsistencies in terminology it was not possible to compare the levels of decomposition for the bodies in that study, to the levels of decomposition for the water cases in this study.

Petrick et al. (2004) performed a similar type of retrospective analysis using 12 coroner and dive team cases recovered from water in British Columbia. The information for the study was taken from survey questionnaires filled out by the coroners or dive team members. The authors did suggest that bodies decomposed faster in flowing fresh water compared to deeper still fresh water bodies. The type of water that the body was recovered in (fresh, salt, sewer) was recorded for the 22 cases in this study, however due to the small sample size; it was not possible to conduct a comparison between cases with equivalent stages of decomposition in different types of water bodies. A larger database of water scene cases is needed to evaluate the impact of flowing, still, fresh and salt water on human decomposition.

Animal proxy experimentation has been conducted by Anderson and Hobischak (2002 and 2004) to investigate decomposition in the marine environment in British Columbia. The results of these studies describing the progression of decomposition for pigs in British Columbia have been provided with the results from this study to illustrate the differences between human and pig decomposition in water (Table 5.1).

Table 5.1. Comparison of pig and human decomposition in water

Stages of Decomposition	**Pigs** – Marine Shallow (time ranges)	**Pigs** – Freshwater running (time ranges)	**Humans** *(mean PMI in days)* *(current study)*
Fresh (stage 0)	0 – 3	0-9	2
Putrefaction (stage 3 – 5)	3 – 11 plus	9-35	47 – 67.8
Skeletonization (stages 6 – 8)	11 – 30 plus	105-182	255
Adipocere formation	40 plus	42-105	190

Note: Pig information taken from Table 1, Pg. 207 (Anderson & Hobischak 2004). The PMI is provided in days.

The mean PMI for the fresh stage or stage 0 decomposition is comparable between pigs and humans. Both the fastest (marine) and slowest rates (freshwater) rates recorded for pig decomposition, is still much faster than the rate of decomposition found in humans. The does appear to be a difference between decomposition of pigs in the marine environment compared to human decomposition in water.

Alternate States of Decomposition in Water: Adipocere Formation

Only two cases out of a possible 27 demonstrated evidence of adipocere formation. This low incidence of adipocere formation is likely due to the shorter PMI intervals and small sample size. The cases with adipocere formation were recovered from cold fast flowing rivers (Figure 4.45). The presence of adipocere was recorded for these two cases at 190 and 321 days (Table 4.10). The earliest occurrence of adipocere for buried cases was slightly earlier, at 154 days. The visible appearance of adipocere in water is more dense and waxy compared to adipocere in buried cases.

In the study by study by Hobischak and Anderson (1999), adipocere was noted on freshwater cases in British Columbia as early as 30 days PMI, but more commonly recorded at 120 days. For cases recovered from Lake Ontario in the central region of Canada, adipocere formation was noted on bodies with a PMI of 22 days up to 5 years (O'Brien 1997). In California, the rate of adipocere formation in freshwater took anywhere from one week to one month (Boyle et al., 1997). The results of the adipocere formation time estimates in this study are relatively consistent with that found by Hobischak and Anderson (1990) with the onset of adipocere from 4 to 6 months. There appears to be an early onset of adipocere formation in other geographic locations. This may relate to lower water temperatures in the summer and winter in Canada which may delay the development of adipocere formation.

5.2. Part II: The Variables Which Affect Human Decomposition in Canada

There were three components to Part II of this study. The first component was to determine which independent variable of time (PMI days) or temperature (ADD score) had more value to predict the progression of decomposition for this dataset. The second component was to determine which other independent variables affected the progression of decomposition, either positively or negatively. A total of 26 variables relating to the bodies environment, immediate context at the scene or specific conditions of the death or individual characteristics were evaluated. The last component was to evaluate whether a complex of variables could be used to explain the majority of the variability in decomposition for that scene type.

5.2.1. *The Value of the ADD Score vs. PMI in Days as a Predictive Variable for Decomposition in Canada*

The variability in temperature is believed to have the most influence over the chemical and biological changes during decomposition (Table 2.7). All biological processes are temperature dependant, the decomposition of tissues via enzyme-catalyzed reactions are no exception (Allison and Briggs 1991). The rate of decomposition increases with temperature to an optimal level above which the enzymatic reactions become inactive. The principle is called "Van't Hoff' rule of ten" or simply, the temperature coefficient Q_{10}. This physical principle states that the velocity of chemical reactions increases two or more times with each 10° C rise in temperature (Gill-King 1997:93). The body operates at a temperature near 37°C during life. The cooling of the body at death affects the enzymes which regulate cellular chemical reactions. These enzymes have an optimal range between 40° to 50°C. A 10°C change will speed up or slow reactions one to three times (Gill-King 1997, Allison and Briggs 1991). Low temperatures can decelerate the progression of decomposition, but high temperatures can denature bacteria and also impede the process.

In a study published in 2005, Megyesi et al. proposed that the temperature was the single most valuable predictive variable for the progression of decomposition. In fact, this study found that the accumulation of temperature accounted for 85% of the progression in the decomposition score. This accumulation of temperature is referred to as the ADD score. In 2005, it was a relatively new concept for those engaged in taphonomic research. It was previously described by Edwards et al., in 1987 and used by Vass to quantify the changes in soil chemistry in a publication in 2002. The ADD score has become popular in recent years as a measure for the progression of decomposition due to the strength of the correlation demonstrated in the study by Megyesi et al.'s (2005).

There have been a number of forensic taphonomy researchers (Fitzgerald & Oxenham 2009, Simmons et al., 2009, Heaton et al., 2009, Bachmann et al., 2010 and Vass 2011) using this method recently with great optimism to account for the majority of variability in the decomposition score without having to account for the countless number of other intrinsic and extrinsic variables. None of these published researchers have achieved the same levels of correlation found by Megyesi et al., 2005. The results of this study found a maximum correlation of 57%, for the ADD score to the progression of decomposition in a set of cases with less than 31 days PMI. The correlation results for the larger dataset, indoor or outdoor, with a PMI of 1 year or less were all less than 50% (Table 4.10).

In this study, there was a slightly better relationship identified between the ADD score compared to the PMI in days for every dataset except the outdoor group with a PMI of 1 year or less (ADD = 43% and PMI = 44.8%) (Table 4.10). For the indoor group, a correlation of 48% was found for the ADD score compared to 45% for the PMI in days (Figure 4.46). For the entire dataset regardless of scene type the results were a correlation of 48% for the ADD score and 37% for the PMI in days (Figure 4.48). The highest correlation results (57%) were achieved for all cases regardless of scene type with a more restricted PMI range of 31 days (Figure 4.49).

An attempt was made to improve the correlations using the same methodology as Megyesi et al. (2005) by conducting a log10 transformation of the data. However, this resulted in overall lower correlations of 28.3% for the ADD score for the entire dataset of cases with 1 year PMI or less (Figure 4.51) and a correlation of 52% for the outdoor cases with 1 year or less (Figure 4.50). Although the regression analysis did find a slightly better correlation of ADD score compared to PMI days for decomposition, the overall correlation percentages are low and have limited predictive capacity.

In the multiple regression analysis, the PMI in days was found to have more predictive value in combination with other variables compared to the ADD score. The multivariable regression analysis identified the PMI in days as a more significant predictive variable in combination with the other variables as opposed to the ADD score in three out of the four scene types (Tables 4.28, 29. 30 and 31). The PMI in days for the three scene types showed a high level of significance with P-values of 0.000 for both water and buried scenes and P-value of 0.002 for the outdoor scenes. These results suggest neither temperature nor time alone can be used as the principle predictive variables for decomposition in Canada. Human decomposition is a complex event which may be better suited to the use of a complex of variables to predict its progression.

The results produced by other studies using the ADD score as the principle predictive variable have been mixed. In a study examining the Times Since Submergence (TSS) estimates for bodies in two major water ways in Great Britain, Heaton et al. (2009) found a correlation of 77% of the ADD score to the progression of decomposition. The ADD score for this study however, was based on actual temperatures taken from the rivers as opposed to historical records from the nearest weather station. The authors of this study did mention that they experienced significant problems with the decomposition scoring system (TBS) as defined by Megyesi et al. (2005), which may have contributed to the lower rates of ADD score correlation. They described the classification of a body as a subjective “best fit” process. It is interesting to note that when Heaton et al. (2009) attempted to create a simple linear regression model for decomposition in water, they found that the model did not apply to all stages of decomposition equally. They actually found more variability in the early stages of decomposition which is opposite to the results of this study that found increased variability in the later stages of decomposition. They attributed this increased error rate to the subjectivity of the total body decomposition scoring system that they used, proposed by Megyesi et al. (2005).

In another study in Great Britain, which summarized much of the data produced by unpublished graduate experiments, Simmons et al. (2010) found a correlation of 67% between the ADD score and the stage of decomposition for animal proxies decomposing outside. However the correlation between the ADD score and level of decomposition for subjects decomposing in other contexts such as underground in burials, inside & submerged in water was much less successful with a level of only 34%.

Fitzgerald and Oxenham (2009) found that the PMI in days was a more valuable predictive variable compared to the ADD score for the decomposition of two pigs in Australia. They found there was a large discrepancy between the temperatures taken at the site for the pigs and the temperatures recorded at the nearest weather station. They suggested that the use of the historical temperatures for retrospective analysis could be problematic and determined that time since death, which includes the accumulation of temperature, is a more appropriate independent variable for decomposition models.

It was initially hoped that the ADD score could equalize the effects of the extreme temperatures and seasonal variability within Canada. However, the ADD score has achieved a very low level of correlation for the progression of decomposition in Canada. The reasons for this may relate to a number of factors including the methods used to calculate the ADD score. This study utilized the same methodology as defined by Megyesi et al. (2005), to add the positive daily mean temperatures for the duration of the PMI. The negative temperatures were not included in this calculation. The impact that freezing temperatures have on a body is not accounted for with the ADD score. This study has demonstrated that cold temperatures do have a negative impact on decomposition, specifically on the processes of putrefaction (Sec. 4.3.4.). This failure to account for cold and freezing temperatures may have contributed to the low levels of correlation found between the ADD score and decomposition in the Canadian dataset. Another issue identified by Fitzgerald and Oxenham (2009) with the ADD score calculations for their study in Australia, was that there was a large discrepancy between the temperatures recorded at the scene and the temperatures recorded at the closest weather station. This discrepancy may have resulted in erroneous ADD scores calculated for the scene which would contribute to the lower levels of correlation.

Another issue which may have contributed to anomalously high levels of correlation for the ADD score and level of decomposition in Megyesi et al.'s (2005) study may have been the bias in the selection of the cases used in the study. The majority of the cases (70%) used by Megyesi et al. (2005) were selected from the authors' own forensic entomology cases. The authors used forensic entomology methodology to estimate the PMI based on the level and extent of insect involvement. Bodies with insect infestation may have a differential rate of decomposition compared to other bodies without insect involvement. The results of this study confirm that insects have a significant positive impact on the progression of decomposition (Table 4.32). There are far fewer cases with insect involvement in this dataset (10%) compared the study by Megyesi et al. 2005 (70%). The study by Megyesi et al., 2005 had a small sample size (66) with eleven of those cases indoor rather than outdoor. Megyesi et al., 2005 used the outdoor temperatures for the calculation of indoor temperatures which may have introduced an error in the ADD calculation based on the affects of air conditioners or heating units.

There have been a number of recent studies (Simmons et al., 2010, Heaton et al., 2009 and Bachmann et al., 2010) which have produced results in relation to the ADD score as opposed to the PMI in days as it relates to the progression of decomposition. The utilization of the ADD score rather than PMI in days as the predictive variable appears to be becoming an expected methodology in experimental forensic taphonomy. This study has not validated the high levels of correlation of between the ADD score and progression of decomposition found by Megyesi et al. (2005). The implication of these results is that future researcher may not be able to rely on the ADD score as the one independent variable responsible for the variability in decomposition, to the exclusion of all others. The results by Megyesi et al., 2005 have not been replicated by any other study in Australia, Britain or Canada with much larger sample sizes and scene specific cases. Based on the low correlation results for the ADD score and the results for the PMI in days using multiple regression; this study has found that the PMI in days is the most valuable predictive variable to quantify the progression of decomposition.

5.2.2. *The Relative Level of Decomposition Value (RLDV)*

The aim of the RLDV was to identify cases which had an anomalously slower or faster rate of decomposition based on the ADD score. The mean RLDVs for all the cases in each scene type were calculated to determine if there one scene type which demonstrated a faster or slower rate of decomposition compared to another. There did appear to be a higher level of negative RLDVs associated to the indoor cases which would suggest a faster rate of decomposition compared to the outdoor cases (Figure 4.7). This finding was confirmed in Table 4.11, where the comparison of the mean PMI in days calculated for each stage of decomposition for each scene type demonstrated a faster rate of decomposition for the inside cases. The distribution of RLDV for the inside outside and water datasets were examined. Stage 5 decomposition for the indoor dataset demonstrated an anomalous skew towards the negative end of the scale which suggests a faster progression through the later stages of putrefaction. The distribution of RLDV for the other scene types was normal (Figure 4.53).

The average RLDVs for a set of cases were used to determine whether the presence, absence or extent of a particular variable such as sex, build, or alcohol consumption would accelerate or decelerate the progression of decomposition. The frequency of negative and positive RLDVs for male compared to female cases did not demonstrate a difference in the overall rate of decomposition (Figure 4.90). However the analysis of the RLDV for differences based on build (Figure 4.95), alcohol use and age did identify a difference (Figure 4.109) which was confirmed by the comparison of the mean PMI or ADD score calculations for these variables. The RLDV therefore did demonstrate a value to identify a slower or faster rate of decomposition based on the presence, absence or extent of a specific variable.

The distribution of RLDV was used to examine the regional or environmental diversity of decomposition across Canada. The lack of clustering based on geographic or ecological variability may suggest that the relative rate of decomposition is dictated by a range of variables, and not on scene location alone. The RLDV results for the comparison between the two main ecozones (8 and 13), did not provide consistent results for the differences in RLDV frequencies between inside and outside scenes (Figures 4.114 & 4.115). This may be due to two factors: an error in the calculation of the original ADD score upon which the RLDV is based, and an error on the RLDV calculation due to small sample sizes.

The error in the ADD score calculation may be due to differences in the temperatures occurring at the scene compared to the temperatures recorded by the nearest weather station and a failure of the methodology to incorporate and compensate for freezing temperatures. With only 358 cases and 9 stages of decomposition for each of the 4 different scene types, the numbers of cases available to calculate the mean ADD score for each stage of decomposition could be relatively few. Some stages of decomposition in some scene types were not actually represented. The review of baseline decomposition demonstrated that there is increased variability in the ADD score with the progression of decomposition after the onset of putrefaction. This increased variability likely contributed to an error rate in the mean calculation used for the RLDV. Although the RLDV does have the potential to identify difference in the rate of decomposition based on the presence, absence or extent of certain predictive variables, a larger dataset of cases would reduce the error rate in the RLDV calculation and increase its power to identify anomalous cases based on a range of factors or variables.

5.2.3. *Environmental Variables*

As a general statement, the Canadian weather is subject to extremes of both heat in the summer and cold in the winter. The contribution of accumulated temperature to the progression of decomposition has been investigated using the ADD score variable. The data set was examined for the impact of cold temperature on the progression of decomposition in Canada. The impact of precipitation was also examined. The total amount of precipitation was calculated for each outside case for the duration of the PMI to determine whether precipitation levels had an impact on baseline decomposition or the formation of alternate states of decomposition such as moulding and adipocere.

The Impact of Cold & Freezing Temperatures on Decomposition

As a result of the temperature extremes within the Canadian climate, the effect of cold and freezing temperatures on the progression of decomposition was examined during this study. Vass (1992) points out that the body does continue to decompose at temperatures less than zero degrees Celsius due the body's salt content. However, only positive temperatures were used with the Megyesi et al., 2005 methodology to calculate the ADD score. The reasons for working with only positive numbers may have been the logistical complication of adding negative numbers to the ADD score. Micozzi identified 4 degrees Celsius, (the normal temperature of a refrigerator) as the temperature threshold where bacterial growth is severely retarded (1997:172). For this reason a group of cases which had been subjected to temperatures of less than 4 degrees Celsius during their PMI were removed from the outdoor dataset to determine what impact the cold and freezing temperatures had on the progression of decomposition.

A set of outdoor cases which had been exposed to minimum temperature of 4 degrees or less, was separated from the larger outdoor dataset. Regression analysis was conducted for both groups to determine whether one had a better correlation with the progression of decomposition compared to the other. This resulted in a correlation of 49% for the ADD score and 48% for the PMI in days for the cold group (Figure 4.54). These results are equivalent to the results for the total outdoor group of 53% for the ADD score 41% for the PMI in days. There is not a large difference in the regression results for the cold group compared to the larger outdoor group.

A comparison was conducted between the cold groups and larger outdoor group in relation to the mean ADD score for each stage of decomposition (Figures 4.55 and 4.56). Both results demonstrated an increased variability at the onset of putrefaction (stages 3 & 4), however it took consistently more temperature for the cold group to achieve each of the later stages of decomposition compared to the normal group. It would appear therefore that exposure to cold temperatures in this dataset did not have an effect on the early stages of decomposition, but resulted in a deceleration of putrefaction (Figure 4.57 & 4.58).

These results support the hypothesis that lower temperatures reduce the activity rate of enzymes and act to denature and destroy enteric bacteria needed during the biological process of putrefaction. A comparison of the time it takes to achieve each stage of decomposition was undertaken (Figures 4.57 and 4.58). As was expected, the cold group took a longer period of time to achieve most stages of decomposition however the cold group took a shorter period of time to reach the earlier stages of skeletonization. The cold temperatures therefore, may accelerate the rate of soft tissue colliquation after putrefaction.

Previous Studies Investigating the Impact of Cold Temperatures

There have been a number of studies which have examined the impact of cold temperatures on tissue deterioration or rates of decomposition (Micozzi 1986 & 1997, Bunch 2009, Tersigni 2006, Komar 1998 and Stokes et al., 2009). Stokes et al. (2009) and Tersigni (2006) conducted controlled experiments on hard and soft tissue in Australia and Hawaii in an attempt to identify changes to the tissue caused by freezing. Bunch (2009) and Micozzi (1986) conducted field experiments with animal proxies in the northern United States of America to examine the progression of decomposition. There is only one study which examined human decomposition in cold environments and it was conducted by Komar in 1998 in the Edmonton region of Alberta, Canada. Komar (1998) conducted a retrospective review of twenty medical examiner cases of bodies decomposing in the extremely cold winter months of northern Alberta.

The results of the study conducted by Stokes et al. (2009) was that freezing small disassociated soft tissue samples did not impact the re-thawed rate of decomposition or the soil chemistry compared to unfrozen samples. This experiment was conduct to determine whether freezing the tissue would be deleterious to forensic chemistry analysis. Tersigni (2006) also found that freezing bone samples did not change the micro-structural integrity of the bone. Exposing these generally sterile samples to freezing temperatures would have a limited effect on decomposition due to the sterility of the sample. Although the disassociated hard and soft tissue samples were not negatively impacted by freezing; freezing would impact the gut flora of an intact human or animal proxy.

There is one study which was conducted using animal proxies to investigate the impact of cold temperatures on decomposition. In a study conducted by Bunch (2009) in the United States, three pigs were placed in three different micro-environments during the winter. Each of the pigs in this experiment decomposed at significantly different rates. The results of this study were that the differences in the rates of decomposition between the three pigs were due more to variability in the micro-environments rather than the sole variable of temperature. The fact that these very small young pigs were dispatched by exsanguination may have also affected the normal progression of decomposition. The age, size and lack of blood in the body may have negatively impacted the amount and ability of the available enteric bacterial to disseminate throughout the body.

A retrospective study conducted by Komar (1998) in the Edmonton, Alberta area examined 20 cases from the Medical Examiner's office. The study concluded that total skeletonization could be achieved outside in that region within six weeks in the summer compared to four months in winter. Only 10 out of the possible 20 cases involved bodies decomposing on the surface. Within that group, 6 out of the 10 cases had been subject to extensive carnivore activity and tissue removal. For the four cases remaining, only two cases had any kind of remaining soft tissue, the other two were fully skeletonized and could have been in that state for a period of time before discovery. The post mortem time ranges for these two cases with remaining tissue were from 1.5 months to 32 months. It is however unknown, how Komar established an average rate of decomposition in winter based on these two cases. It is also not know how the six week summer rate of decomposition was established as all the cases in her study were selected because they were known to have died and decomposed during the winter months. The study conducted by Komar (1998) is the only one which has attempted to investigate the impact of cold temperatures on human decomposition. Due to the small sample size and the extensive scavenging of the subjects in this study, very little is known about the impact of cold temperatures on the decomposition of soft tissues.

Freezing Temperatures and Alternate States of Decomposition

Micozzi's (1986) stated that freezing temperatures will act as a biocide to eliminate or slow down endogenous gut flora and thus result in a slower rate of decomposition, and may result in the re-colonization of aerobic bacteria on the body from external sources. The deceleration of decomposition and external colonization was observed for one case in this study. The body was exposed to freezing temperatures (to a minimum of -11 degrees) with an average temperature of 4 degrees during the 37 day post mortem interval (Figure 4.119). There was no visible sign of *normal* autolysis or putrefaction for this case with discolouration or distension of the soft tissue. There was however an obvious colonization of the tissue by an unidentified algae[1]. The visible appearance of the body in this case could be consistent with Micozzi's (1986) prediction that bodies exposed to extreme cold will decompose from the 'outside in' versus the 'inside out'.

It has established by this study that there is a quantifiable impact of cold and freezing temperatures on decomposition in Canada. The cold temperatures appear to have a limited impact on the outward visible signals of autolysis however it contributed to a deceleration in putrefaction. Cold temperatures affected the processes of autolysis and putrefaction differently. In relation to the temporal progression of decomposition, cases exposed to cold and freezing temperatures have a higher likelihood of lingering in the later stages of decomposition but achieving skeletonization sooner than their warmer counterparts.

[1] Photos of this case were reviewed by Prof. David L. Hawksworth CBE (Forensic & Environmental Mycologist). Dr. Hawskworth speculated that it was likely an algae colonization but was unable to be more specific.

The implication of these results is that death investigators in Canada must consider the detrimental effect of freezing or cold temperatures on putrefaction and the later stages of decomposition. A body which has overwintered and possibly been subject to freezing temperatures may have a different rate of colliquation compared to a body with an equivalent overall ADD score not exposed to freezing temperatures. There may be instances where a frozen body will not putrefy. In the cooler moist and dark environments of western Canada, there could be instances of bodies colonized by fungi or algae in a relatively fresh state after a long post mortem interval.

The Impact of Precipitation on Decomposition

The level of moisture is a variable which is difficult to quantify at death scenes. Humidity is a measure of relative moisture in the air, which was not quantified for these death scenes in this study. The level of soil moisture for human remains recovered from clandestine graves is also a variable which has not been quantified for this retrospective study. The only measure available in relation to the level of moisture was the total accumulated precipitation that a body was exposed to in the outdoor scenes. This provided a measure of the moisture that the body may have been exposed to during the PMI; however it is not a measure of humidity.

For the majority of cases in this study, the body was exposed to between 0 and 10 mm of precipitation (56%) (Figure 4.59). The geographical region (ecozone) with the highest amounts of precipitation was the Pacific Maritime (58% of all precipitation) (Figure 4.60). For this study, the impact of precipitation was examined as a single independent variable. The correlation between total precipitation and the decomposition score provided a P-value of 0.509, which is not significant (Table 4.13). The stepwise regression examining precipitation with the PMI in days found that the increasing amount of precipitation appeared to have a slight positive impact on decomposition with a combined value of 0.005 which is significant (Table 4.14).

The variable of precipitation was evaluated in combination with five other environmental, immediate context or intrinsic variables and resulted in a correlation of 83% for the variability in the decomposition score outside (Table 4.28). The P-value for precipitation in this model was only 0.215 which is not considered significant. However precipitation was found to contribute to the model sufficiently to be retains as one of the

7 predictive variables. The result of the analysis was that precipitation as an independent variable did not significantly contribute to the rate of decomposition. There is a measurable contribution of precipitation when included in a complex of other variables outside; however, it is proposed that this contribution is related more to the outdoor humidity rather than precipitation.

Previous Studies Relating to Precipitation and Decomposition

There is only one published study which has investigated the potential impact of precipitation on the processes of decomposition (Archer 2003). The study utilized a number of still-born piglets in Victoria, Australia to assess what impact temperature and precipitation had on the reduction of body mass over time. Regression analysis was conducted for the levels of temperature and precipitation against the reduction of body mass (which was presumably associated with the progression of decomposition) for periods of time. The study examined the progression of decomposition over two periods of time; the first six and the second six day periods for a total of twelve days. The study found that the rate of body mass loss was accelerated after the first 6 days which correlated to the increase in temperature and precipitation during that time period. Unfortunately no controls or repeated studies were conducted to ensure that this increased weight loss was related to temperature and precipitation or temperature alone.

The weight loss after the first 6 days may have been the result of the natural processes of colliquation after putrefaction, independent of the precipitation or temperature variability. It is also important to note that in a cost saving measure, still-born piglets were used for this study. Still-born pigs would have lacked gut-flora and any endogenous bacterial present on the body would have been introduced externally from the mother in the birth canal. The lack of gut flora for these animal proxies confined the comparison of these results to newly born human babies. In the forensic setting, the starting weight of a baby born clandestinely and then disposed of is generally not known.

Mann et al. (1990) conducted a review of all the variables which affect human decomposition based on their anecdotal observations of human decomposition. The review briefly discussed the effects of precipitation on bodies decomposing at the Anthropological Research Facility (ARF) in Knoxville, Tennessee. They concluded that precipitation had no effect on the maggot activity which they attributed to be the main agent of human decomposition. They did not discuss precipitation as it might affect other agents of decomposition such as bacteria or fungi. They did however offer an observation that that heavy "hard pelting rain" (Mann et al. 1990:105) could slough skin from a cadaver.

Previous to this study, there was very little known about the effects of precipitation on the process of decomposition. This study has found that precipitation does have a minimally positive impact on the progression of decomposition when it is evaluated with a number of other variables. The value of the cumulative precipitation variable is likely related to the impact of ambient humidity at the scene as opposed to the impact of liquid rain.

5.2.4. *Immediate Context Variables*

The immediate context variables are the specific micro-environmental conditions or circumstances specific to the body at that scene. These variables include the extent of clothing or shrouds, the exposure of the body to the sun and impact of insects and scavengers. These variables were selected based on the availability of the data and ability to quantify the data based on case information and photographs.

The Impact of Clothing & Shrouds

The impact of clothing on the progression of decomposition is still relatively unknown. There does not appear to be an agreement in the literature over whether clothing accelerates or decelerates the rate of decomposition. Rhine and Dawson (1989) have stated that heavy clothing will accelerate decomposition, however tight clothing will slow it down. Galloway et al. (1989) found that bedding and clothing retarded the rate of decomposition especially in the early stages. Komar (1998) also observed in her retrospective study that clothing appeared to protect tissues from environmental extremes and damage by scavengers which retarded the decay rate. Mann et al. (1990) stated that clothing sped up the processes of decomposition as the coverings protected the body from sunlight and insect colonization.

There was an equal number of clothed versus unclothed cases in this study (Figure 4.62), which provided an opportunity to address the question of the impact of clothing in relation to decomposition in Canada. Mean ADD scores were calculated for the clothed versus unclothed groups. A comparison of the mean ADD scores did not demonstrate a significant difference (P-value of 0.879) (Table 4.19) in the temperature needed for each of the stages of decomposition between the two groups (Figures 4.63 and Table 4.18). The mean PMI in days was calculated for the clothed versus unclothed groups found a decrease in the mean PMI days required to reach each stage of decomposition for the naked group (Table 4.16). The difference in the PMI (in days) results for the clothed and naked groups were not determined to be statistically significant with a P-value of 0.620 (Table 4.17).

The impact of clothing was examined for bodies decomposing in a water context. A comparison was made of the PMI (in days) and ADD scores for each of the clothed and unclothed groups to achieve stages 2 and 4 decomposition. For the naked group, it took more time (PMI in days) and temperature (ADD score) to reach stages 2 and 4 compared to the clothed group (Table 4.20). These results should be viewed with caution due to the small sample sizes. As an independent variable, the presence of clothing does not appear to have a significant impact, either negative or positive, on the progression of decomposition.

The multivariate analysis which included all variables for the four scene types identified clothing as a contributor to decomposition in burial environments with a significance of P-value 0.004 (Table 4.30). An increase in the extent of clothing for buried bodies resulted in a decrease in the rate of decomposition. Overall, this study has found that the extent of clothing has a limited affect on decomposition in most scene types. Although clothing was identified as a contributing variable in burial environment, it was not identified as a predictive variable in the water. The results of this study are consistent with the preliminary results of Heaton et al. (2009). In the retrospective study evaluating decomposition in water, (Heaton et al., 2009), a difference was detected in the rate of decomposition between clothed and unclothed bodies, however due to the under-representation of unclothed bodies in the dataset (9%) they suggested using caution with those results.

The Impact of Shrouds on Decomposition

Shrouds and clothing have generally been treated as the same variable in the literature (Galloway 1989); however for this study, shrouds have been treated as a separate variable from clothing. Shrouds are defined as the coverings that the body was wrapped in at the time of discovery. These shrouds can include items such as plastic bags, sleeping bags, mattresses or debris. The type of shroud was divided into breathable, non-breathable or mixed to assess the impact of shrouds on the progression of decomposition. Only 54 cases in the dataset had any type of shroud. The most common type of shroud in this study was breathable sheets, blankets or sleeping bags (40 cases). Only 9 cases in the study were discovered wrapped in a non-breathable shroud such as a plastic bag and a small number of cases wrapped in shrouds of mixed breathability (5 cases). (Figure 4.64).

The mean ADD scores were examined for stages 1 and 2 for the groups with and without shrouds. For stage 1 decomposition (Figure 4.65), there did not appear to be a difference between the groups with and without a shroud, however the group with the non-breathable shroud at stage 1 did demonstrate a lower mean ADD score and therefore faster rate of decomposition compared to the other groups. There was very little difference in the mean ADD scores calculated for stage 2 decomposition (Figure 4.66). However, the group without a shroud had a much higher mean ADD score and therefore a slower rate of decomposition.

There is only one study in the literature which conducted an investigation into the potential impact of non-breathable shrouds on decomposition (Pakosh and Rogers 2009). This study utilized dismembered pig limbs and compared the process of decomposition of limbs fully submerged in water, in and out of plastic bags. The result of the study was a reduced level of decomposition for the samples in plastic bags, which was attributed to an inhibition of bacteria and low oxygen levels. The results of this study suggested a deceleration in the rate of decomposition for bodies found in non-breathable shrouds. These results are in conflict with the results of this study perhaps due to the type of subject material. The internal decomposition of an intact human with anaerobic bacteria is very different from the external decomposition of a tissue sample by way of aerobic bacteria. The extent of clothing appears to have a limited impact on the overall progression of human decomposition in any scene type. A body wrapped in a plastic bag may experience a slightly faster rate of decomposition. Based on the results of this study, it may be possible to exclude clothing and shrouds as a significant predictive variable for the progression of decomposition.

The Impact of Sun Exposure on Decomposition

There has been very little published research relating to the impact of sunlight on human decomposition. In their general observations of human decomposition, Mann et al. (1990) did not identify sun exposure as an influential factor. Rhine and Dawson (1989) however, in their retrospective analysis of 35 cases in the southwestern United States suggested that sunlight did act to speed up the rate of decomposition.

There is an equal representation of outdoor cases in the full sun (36%), in partial shade (30%) and in full shade (33%) in this study (Figure 4.67), which afforded the opportunity to evaluate the impact that sun exposure has on decomposition in Canada. Contrary to Rhine and Dawson (1989), the results of this study were that decomposition appeared to be faster in total shade compared to full sunlight using both the PMI in days and the ADD score (Figures 4.68 and 4.69). The cases in partial shade achieved the slowest rate of decomposition using both the ADD score and the PMI in days (Figures 4.68 and 4.69). It would appear therefore, that in the Canadian environment, the total shade affords the optimal conditions for decomposition as opposed to full sunlight, even with the elevated temperatures in full sunlight. This might be due to higher humidity levels in shaded environments.

These results coincide with Bass' (1997) observations of 30 years of decomposition at ARF in Knoxville, Tennessee. He identified high heat, humidity and shade to be the optimal conditions for maggot infestation, and from his perspective, the optimal conditions for decomposition. The impact of insects as it related to the extent of shade was investigated during this study. It was found that there was no specific preference of insects to bodies in the shade or full sun in Canada (Figure 4.70). When the extent of sunlight was examined within a complex of other variables outdoors, it was excluded from the stepwise regression as a significant predictive variable (Table 4.33).

There have been multiple forensic entomological studies using animal proxies to test whether or not sunlight has an impact on insect colonization and subsequent tissue consumption by those insects during decomposition. The methodology for these experiments included the use of only two pigs; one in the sun and the other in the shade. One of the most frequently quoted studies was conducted in Washington State, in the United States (Shean et al., 1993). This study found that the pig in the sun decomposed at a much faster rate compared to the one in the shade. The study suggested that the increased ambient temperature increased insect involvement and thus accelerated decomposition. In Australia, Fitzgerald and Oxenham (2009) found that sunlight had no significant effect on decomposition. In Saskatchewan, Canada, Sharanowski et al. (2008) found that the extent of sunlight only affected the extent of insect colonization of the pigs during the spring, with no discernible impact observed during the summer and fall. Two other independent studies in Argentina (Conteno et al., 2002 and Battan Horenstein et al., 2010) confirmed the findings of Sharanowski et al. (2008) that sunlight had a limited affect on insect infestation and subsequent decomposition.

The results of this study suggested that bodies decomposing in a shaded environment may have a faster rate of decomposition in relation to both mean PMI days and lower mean ADD scores. This increased rate of decomposition in the shade is likely the result of increased humidity levels as opposed to increased insect involvement.

The Impact of Insects on Decomposition

Many taphonomy researchers believe that insects and scavengers have a significant impact on the rate of decomposition (Table 2.7). Scavengers and insects do participate in the removal of tissue when they are present; however the involvement of either at Canadian death scenes was limited (Figure 4.71). The presence of insects, or impact of insects, was visible in only 15% of cases outside on the surface, and 7% if the cases inside. The distribution of cases with and without insect involvement was not limited by geography (Figure 4.71) or season (Figure 4.72).

Forensic crime scene investigators would expect a lack of insects on bodies during the winter months; however the absence of insects both inside and outside cannot be attributed entirely to the seasonal fluctuations in Canada. The majority of cases located without insect infestation were found during the summer months (Figure

4.72). Another expectation of forensic crime scene investigators is that insects would lay their eggs on a body very soon after death or exposure of the body. This study has discovered that there can be a large time delay in the arrival of insects, even the ones exposed outside during summer months. The mean time delay for the arrival of insects was 5 days for the cases outside, and 3 days for bodies located inside (Figures 4.73, 4.74 and 4.76). Bodies were discovered inside and out, without any visible signs of insect colonization or tissue damage from the day of death to a maximum of 85 days indoors and 360 days outdoors (Figure 4.74).

The late arrival of insects to a body may not be as surprising as they appear. A study by Anderson (2010) examining insect colonization indoors during the summer in Alberta produced similar results. Anderson (2010) conducted an experiment using animal proxies to examine the differences in insect colonization and decomposition outside versus inside in the Edmonton, Alberta region of Canada. Six pigs were placed in various rooms in a condemned house and three outdoors. The condemned house did not have any windows or doors, which made insect access to the pigs possible. Although there was an immediate colonization of the pigs outdoors shortly after deposition; the study found a 5 day delay for insects to colonize the pigs indoors (Anderson 2010:139).

Forensic Entomology and the PMI

The general assumption in forensics is that flies oviposit on the body within a few minutes after death (Fisher 1973) and as such, entomology is believed to have considerable value in determining the time of death (Shepherd 2003). Rhine and Dawson (1989), Bass (1997) as well as many others have stated that the presence and action of insects speeds up decomposition. These assumptions are based on field experiments using pigs as proxies for humans. The research with the pigs does appear to support the assumption of an immediate colonization by insects, however, the results of this study suggests that that might not be true for humans.

This is not the first retrospective study to note the conspicuous lack of insects on the body at the scene. In the second biggest retrospective analysis of human deaths in Arizona, Galloway et al. (1989) stated that “no insects could be detected from the photographs” (1989:610). They also stated that there was a “difficulty of insects to infest remains" (1989:612). Unfortunately, there was no explanation provided for the lack of insect infestation for cases in that study. In the only other retrospective study conducted in Canada, Komar (1998) commented that insect activity could not be reliably determined from photographs. Another retrospective study by Sorg et al. (1998), recorded 13 out of a possible 34 cases where no live insects or larvae were located on the body at the point of discovery. A retrospective study involving 187 bodies recovered from two water ways in Great Britain reported that there was no insect activity associated with any of the remains (Simmons et al., 2010). Hobischak and Anderson (1999) were self admittedly surprised when only 3% of the retrospective cases recovered from water in BC demonstrated any sign of insect involvement. The authors attributed this absence of insect evidence in the reports to poor collection techniques and an ignorance of the importance of insect evidence.

It is unknown what type of photographs or documentation these other retrospective studies had access to, they may have been limited to scene photographs or autopsy reports without photographs. There may be an issue with the identification of insects solely based on crime scene photographs. This study attempted to address that issue by examining the autopsy photographs in addition to crime scene photographs. Often any insects hidden within the clothing or within the body will travel to a more exposed and visible location after a period of time within a body bag. The initial photographs taken when the body bag was opened were examined for insect activity and the photographs taken at autopsy examined to determine whether there was any tissue consumption as the result of insect activity.

The reason for the delay in the arrival of insects may be due to the weather conditions. Cloudy, rainy or windy conditions may not be suitable for the arrival of the flies to lay their eggs. Entomologists will often look at the "windows" available for insect activity (Pickering & Backman 2009) and provide minimum limits for insect infestations. It is not known how objective the determination of the "window" is, or whether there is enough known about these species to predict behaviour based on weather conditions.

In relation to the impact of insect colonization and the progression of decomposition, Simmons et al. (2010) published a study which amalgamated much of the published and unpublished data on decomposition in Britain conducted by students at Bournemouth University. The advancement of decomposition was measured by the ADD score. The variables of build and insect activity were evaluated as predictive variables for decomposition in this study. The authors made the assumption that insects were entirely excluded from indoor, buried and water scenes, which explained the failure of the ADD score to predict decomposition in those scene types. The differences in the regression slopes between the ADD score and decomposition value were entirely attributed to the involvement of insects as the main agent of decomposition outside. Build, or body size was therefore determined to be an important variable purely as a source of food for the insects outside.

This study represents the largest number of retrospective cases outdoors or indoors and has found only a 7% involvement of insects indoors and 15% involvement outdoors. The population levels of insects and extent of colonization by insects may be specific to the Canadian ecozones, however the assumption cannot be made that insects are the primary agent of decomposition (or tissue consumption) and that colonization outside is a given.

The multivariate analysis of insects as a variable did identify it as having a significant impact on the advancement of decomposition both indoors and outdoors with a P-value of 0.000. However, this only represents the small number of cases with insect involvement. Only 10% of the total cases recorded the presence of insects, but for that 10% of the cases, insects as a variable it did have a significant impact on decomposition. For the majority of cases in the Canadian dataset, insects had no visible involvement and therefore no impact on the speed and progression of human decomposition.

The implications of these results may be fairly significant to the utilization of forensic entomology to calculate PMI estimations in Canada. It would seem that there is an onus on forensic entomologists in Canada to substantiate the two fundamental premises of their discipline; that the decomposition and colonization of insects on pigs is analogous to humans, and that insects arrive on a corpse within a predictable period of time.

The Impact of Scavenging on Decomposition

Another unexpected result of this study was the low incidence of scavenging and secondary predation observed for cases in this study. There were only 27 cases which exhibited signs of scavenging damage to the body on the day of discovery (Figure 4.78). Five of those cases include water cases which exhibited tissue damage due to marine scavengers. The analysis of the mean ADD score and PMI days for the appearance and extent of scavenging did not reveal any relationship between time and the level of decomposition with the presence or extent of scavenging (Fig. 4.77 and 4.79). The terrestrial scavenging was not dependant on the season (Figure 4.80), or the passage of time. The results demonstrated a relatively low incidence of scavenging for the outdoor dataset and the timing of the scavenging suggested an opportunistic as opposed to probabilistic pattern of involvement.

Haglund (1997) conducted a retrospective study of scavenging in the Northwest region of the United States and discovered a lack of predictability in the timing of scavenger involvement, with some bodies being extensively consumed and others ignored in the same immediate area. Sorg et al. (1998) commented that they were surprised during their review of human cases from the northeastern United States, that bodies in areas where scavengers were known to frequent were often left untouched. The study suggested that some of these bodies had remained intact due to the advanced level of decomposition which would have made the bodies unappealing to scavengers (Sorg et al., 1998). However, Galloway et al. (1989) found that the majority of the damage inflicted by scavengers, to carcasses after death in Arizona, was during the advanced decomposition and initial mummification stages. Sorg et al., 1998 proposed that bodies deposited outside in the fall were less susceptible to scavenging, whereas the bodies exposed during the late spring and summer had the highest likelihood of scavenging. A seasonal pattern of scavenging was not found for the cases in this study (Figure 4.80).

There are a range of species responsible for the consumption of tissues from bodies exposed outside in Canada. Komar and Beattie (1998) conducted an experiment on scavenging near Edmonton, Alberta and found that one of the first scavengers to impact a pig deposited in that area was the magpie. These avian scavengers continued to feast on several pigs for up to 30 days. The study found that it was not until after the birds had abandoned the carcasses that the *canids* began to scavenge. In Edmonton, domestic dogs and magpies were seen feeding on the same cadaver side by side. It is interesting to note, that although 3 pigs in this study suffered extensive scavenging damage and dispersal, 5 pigs were scavenged by birds alone, and the remaining 16 pigs experienced minor to moderate avian scavenging only in the very late stages of decomposition and skeletonization. The tremendous impact of avian scavenging was also seen in an animal proxy study conducted in Texas (Reeves 2009) where vultures reduced pigs to bones in a matter of days. Komar (1998) found that of the 10 cases she reviewed in northern Alberta, the majority of them had been subject to scavenging activity. The study by Komar and Beattie (1998) suggested that scavengers in Canada were selective and unpredictable with arrival times and extent of scavenging fluctuating over large periods of time. The findings of Komar and Beattie (1998) have been verified by the results of this study.

In the multivariate analysis of variables affecting decomposition outdoors, scavenging was identified as a significant variable (P-value of 0.000). Willey et al. (1989) suggested that the impact of scavenging should be taken into consideration when estimating PMIs. The results of this study support that suggestion. For the 17% of the cases which were impacted by scavengers, it had a positive and significant impact on the rate of decomposition. However, 83% of the cases decomposing outside on the surface throughout the year were not impacted by scavenging. Scavenging appears to be an unpredictable and opportunistic event for human remains in Canada. A body can remain intact and untouched in an area with scavengers for an extended period of time during any season; however, another body in the same area can be subject to extensive scavenging and destruction. The extent of scavenging therefore cannot be used as an indication of the length of the PMI, or season of deposition in Canada.

The Impact of Level of Submersion on Decomposition in Water

The impact of the level submersion on the progression of decomposition was evaluate not as an independent variable, but within a complex of variables due to the small sample size of water cases. The more submerged the remains on the day of discovery, the slower the rate of decomposition. The stepwise regression found the level of submersion to be significant with a P-value of 0.023 (Table 4.31). Human remains however may move vertically within a body of water throughout the progression of decomposition. There have been a number of studies conducted on the postmortem submersion and transportation of bodies in water ways in North America (Bassett et al., 2002, Ebbesmeyer & Haglund 1994 and Lucas et al., 2002) as well as the United Kingdom (Heaton et al., 2009). The study conducted on bodies recovered from the British waterways found that the level of submersion of the body under water at the time of discovery also had a negative impact on the rate of decomposition (Heaton et al. 2009).

5.2.5. ***Intrinsic Variables***

The Intrinsic variables consist of the circumstances specific to that individual, and the conditions surrounding their death. These variables include: age, sex, build, manner of death, type of trauma and extent of blood loss, if any. The occurrence and extent of drugs and alcohol consumption by the victim around the time of their death is also considered to be an intrinsic variable.

The Influence of Age on the Progression of Decomposition

The influence of a victim's age on the process of decomposition is a variable that has not been previously investigated in relation to human decomposition. The one biological difference between age groups that may have a direct impact on decomposition is gut flora. In a new born, the gut flora is absent. The frequency and complexity of the gut flora increases as the individual matures (Anderson et al., 1974). Sears (1996) stated that the balance of bacterial colonies change over time, with a switch from the dominant E.*coli* to B. *fragilis* as the individual matures. Due to the lack of research in this area, the timing of this transition is uncertain.

The distribution of ages in this study was from foetal to 97 years (Figure 4.82). An evaluation of the mean ADD scores calculated for each age set for each stage of decomposition study found that the early stages of decomposition were accelerated for infants, children and seniors compared to adults (Table 4.83). There are only 7 cases in the dataset with an age of 1 year or less. The longest post mortem interval for this group was 5 days. There was only one case in an advanced stage of decomposition; a foetus in a clandestine grave which was found in the last stage of putrefaction (stage 5). The other cases were discovered at a relatively early stage of decomposition. Due to the small sample size, it is unknown how long babies will remain in this fresh state prior to the onset of putrefaction. The baby and child cases demonstrated a delay in the time it took to progress through the stages of autolysis into putrefaction (Figure 4.84). Comparatively, adults progressed into putrefaction consistently sooner than the children and babies (Figures 4.85, 4.86, 4.87 and Table 4.25).

It was noticed that the babies under the age of 1 year old had a much higher frequency of tissue desiccation and mummification with at 50% incidence compared to 10% for the older age groups. It appeared that babies had an earlier onset of mummification with a delay in putrefaction which could be attributed to a lower count and complexity of gut flora. Allison and Briggs (1991) recorded a differential progression of decomposition in stillborn animals due to their lack of natural gut micro-biota and lung contamination. In relation to the experimental decomposition of stillborn piglets, Allison and Briggs (1991), found that the subjects tended to mummify as opposed to putrefy as seen in the adult pigs. Janaway also noted that mummification occurred more frequently in babies and small children given the same environment as adults (1996:70). Janaway stated that this mummification was not permanent, but delayed until the external bacteria had a chance to colonize given a moister environment (*Ibid*).

There is very little available published information on the potential impact of age on the progression of human decomposition. Only one published study used age as a variable in an animal proxy experiment near Victoria, Australia (Archer 2003). The use of neonatal pigs in this study may have been more due to economics as opposed to an experimental design. Adult pigs cost considerably more than the still-born pigs which were free. The study found that based on past experience examining decomposition in adult pigs and humans, the decompositional patterns in neonatal pigs was different. The study noted that late stage purification was relatively odourless and tissue liquefaction was almost complete. These differences were attributed to the relative lack or reduction of gut microbes in neonatal pigs. Archer (2003) cautioned that care must be taken when comparing human babies and the decomposition of neonatal pigs as the two subjects are very different.

The Relationship between Age Group and Trauma

The dataset was divided into age sets and groups of 10 years from 0 to 100. To determine what impact age has on the progresses within decomposition, an analysis was conducted for the progression of autolysis and then putrefaction for the age groups. For the initial stages of decomposition (stages 0 to 2), the two youngest age groups demonstrated a faster rate of decomposition in PMI days compared to the adult age groups (Figure 4.88). What was unexpected was the anomalous result for the 20 to 30 age group. The results displayed a very high mean PMI in days which represented a slower rate of decomposition for this age set. It was suspected that this dramatic deceleration in autolysis for the 20 to 30 age group could not be attributed to age alone.

An examination of the manner of death for each age group provided a possible explanation for this anomalous result. There was a noticeable concentration of traumatic death for this age group compared to any other (Figure 4.89). The incidence of homicide and violent death was much higher for the 10 to 30 age groups. The manner of death and subsequent extent of blood loss could have been a significant contributing factor in the deceleration of autolysis in this age group. Blunt and sharp trauma was the most common method of homicide in the Canadian dataset which resulted in moderate to high levels of blood loss (Figure 4.102). It is proposed that the degree of blood loss contributed to the deceleration of autolysis in the 20 to 30 age set.

This is the first study to investigate the differential rate and state of decomposition between the age groups. This study has found an increased level of mummification and preservation with a delay in putrefaction for babies under the age of 1 year. This progression of decomposition in babies is likely due to the limited amounts and complexity of enteric gut flora. This potential to increased tissue preservation in babies may influence search and recovery strategies for abandoned new born babies. The recovery of the infant and determination of live or still-born death at autopsy is critical to a criminal investigation. The dramatic deceleration of autolysis in individuals between the ages of 20 to 30 could be contributed to blood loss as opposed to frequency of gut flora. The impact of blood loss on the progression of decomposition will be discussed in a further section.

Variability in Decomposition between Males and Females

Even though there are structural and bio-chemical differences between the sexes; it is not known how those differences translate into variability in the progression of decomposition. Females were under-represented in this study with 132 females versus 226 males. The RLDV was used to examine differences in the relative rate of decomposition by sex (Figure 4.90). It was found that there was no quantifiable difference in frequency or distribution of RLDV based on the variable of male or female. The analysis of the relative frequencies of RLDV with 1 or 2 standard deviations above or below the norm provided equivalent results for both sexes (figure 4.90).

A comparison was made of the mean ADD score needed for the male compared to the female group for stage 1 decomposition. The results suggested that females took more temperature and perhaps more time to achieve stage 1 compared to males (Figure 4.91). This slightly slower rate of decomposition for the female group was repeated when all stages of decomposition were examined (Figure 4.92). There was however a better correlation of the PMI (in days) to the decomposition score with the female group (46%) indoors compared to the male group (35%) (Figure 4.93). The only other difference between the sexes for the natural deaths indoors; the males were much more likely to die with a television remote control in their hands (7%) than women (0%).

The male group did demonstrate a steady progression of mean ADD scores compared to the more variable progression of the female group (Figure 4.92). This difference may be the result of a smaller sample size for the female group. A *t*-test of the differences in the mean ADD scores between the sexes resulted in a P-value of 0.5, which is not statistically significant.

There are very few studies in the taphonomy literature which have even commented on sex as being a potential variable in decomposition. The study conducted by Prieto et al. (2004) in Spain with 29 cases, found that sex differences did not correlate to any differences in decomposition. Little weight has been placed on the importance of sex as a predictive variable based on the amount of published research on the topic in forensic taphonomy. The results of this study confirm that biological sex does not appear to have a significant impact on the progression of decomposition for the cases in this study. It may now be possible to discount sex as a contributing variable for human decomposition.

The Impact of Body Build as a Variable in Decomposition

There does not appear to be consensus in the literature in relation to the affect that build has on the processes of decomposition. It has been proposed, that the larger the body, the more time it takes to decompose (Pickering and Backman 2009). However, Fisher (1973) suggested that obesity tended to accelerate the rate of decomposition. Shepherd (2003:46) has proposed that thinner individuals will mummify and desiccate more rapidly as the body will cool faster. Prieto et al. (2004) did not find that constitution was in any way correlated to decompositional change in his retrospective analysis of 29 cases in Spain.

The proportion of cases with the range of body sizes from thin to obese was reflective of the normal Canadian population, with normal body sizes being at 51% and the more extreme types in the minority (Figure 4.96). The mean RLDV was calculated by build type and the distribution of build type mapped across Canada to identify any geospatial patterns or concentrations of RLDV based on build. There did appear to be a higher frequency of cases in the obese group with more than 2 standard deviations from the norm, suggesting potentially an anomalously faster or slower rate of decomposition based on build type. The distribution of RLDV according to build appeared to be relatively equal across Canada (Figure 4.95). There was a slightly elevated concentration of larger build sizes in the Halifax region which is likely proportionate to the body sizes in that geographic region. The 2007/8, the self-reported obesity rates were the lowest in British Columbia at 12.8% and highest in the Newfoundland and Labrador province at 25.4%. Nova Scotia was only slightly behind Newfoundland and Labrador at 23.2% (Health Living – Public health agency of Canada: http://www.phac-aspc.gc.ca accessed on 09/12/2012).

The mean ADD scores were calculated and compared for the sets of cases by build with limited results (Figure 4.96). For the thinner individuals, the mean ADD scores for each of the stages of decomposition appeared to remain constant for the later stages of putrefaction and skeletonization. The mean ADD score for each stage of decomposition for the thinner cases was generally lower (which suggest a faster rate of decomposition) than the average in the later stages of decomposition. The regression analysis of variables affecting decomposition outside identified build as a contributing variable with a significance of P-value =0.006 (Table 4.28). Body size was not identified as a contributing variable in any of the other three scene types, or within the total dataset regardless of scene type (Table 4.33).

In the synthesis study conducted by Simmons et al. (2010) they found that body size and insect involvement were the sole contributors to the progression of decomposition. Their study found that body size was only a contributing variable in the outdoor dataset as a food source for insects during the progression of decomposition (Simmons et al., 2010). This study did not identify build as a significant variable in all scene types. The logic that body size is only a factor in the outdoor scenes as a food source for insects is inconsistent with the results of this study due to the limited involvement of insects outside (17%) and presence of insects inside (7%). Build does not appear to be a significant predictive variable for decomposition; however it may play a contributory role in the complex of variables affecting decomposition outdoors.

The Impact of Trauma and Blood Loss to Decomposition

There is a range of differing opinions in the literature regarding the role that trauma plays in the progression of decomposition. Many researchers believe that insects are attracted to trauma sites and the increase in insect activity relates to an increased rate of decomposition (Mann et al., 1990). Galloway (1989) commented on a study by Burger (1965) that blow flies were less attracted to postmortem incisions and trauma sites, than to the natural body orifices. Fisher (1973) suggested that since blood is an excellent medium for bacterial growth, trauma would accelerate decomposition at a specific injury site. It’s unknown whether Fisher was suggesting a florescence of bacteria associated to the presence of blood inside or outside the body.

The result of the investigation into the impact of blood loss on the progression of decomposition in Canada has been astounding. Blood loss was found to be a significant contributing variable in all scene types apart from water. The lack of results for the water scenes was only due to the inability to assess the amount of blood loss due to the context. Table 5.2 provides the summary of the results from the multivariate regression analysis involving all variables for the four scene types.

Table 5.2. The summary of P-values for blood loss at each scene type except water

Scene Type	P-Value
Outdoors	0.219
Indoor	0.006
Buried	0.054
All scenes	0.020

Note: in all instances the greater the extent of blood loss the more negative the effect on the progression of decomposition. The information for this table was taken from Figures 4.28. 4.29, 4.30 and Table 4.32)

The extent of blood loss was found to be a significant variable for indoor cases and all cases regardless of scene type. Blood loss was identified as a contributing variable for the outdoor and buried scenes (Table 5.2). Apart from time PMI in days, blood loss was the most frequently identified variable for almost all scene types in the Canadian dataset (Table 4.33). The relationship of blood loss to the progression of decomposition in all cases is a negative one. As the extent of blood loss increases, the advancement of decomposition decelerates.

The results of this study have identified a correlation between the type of trauma and extent of blood loss. Moderate amounts of blood loss have been attributed to blunt force and ballistic trauma. Extreme blood loss was almost exclusively associated with sharp trauma (Figure 4.102). Blunt force trauma is the most common type of trauma in the dataset (21%), followed by ballistic (15%) and then sharp (14%) trauma (Figure 4.97). Sharp trauma was associated to suicides or homicides, whereas blunt force trauma was generally associated with homicides (with the exception of suicide by jumping from a height). It is unknown how reduced volumes of blood biologically decelerate decomposition; however it is suspected that the lack of blood negatively impacts the ability of the bacteria to disperse throughout the body as suggested by Bell et al., 1996 and Bell 2012.

The mean PMI in days was calculated for each of the trauma types for stage 0 and 1 decomposition (Figures 4.99 and 4.100). A comparison was conducted to determine whether a specific type of trauma had a slower or faster rate of decomposition. Sharp and blunt force trauma, the two trauma types with the highest level of blood loss were both associate to a faster rate of decomposition for stage 0 and 1 compared to any other trauma type.

Mant (1987) conducted 150 World War II exhumations and observed that traumatized bodies would skeletonise faster than more intact ones, given the same environmental conditions. He noted that wounding would make cadavers more susceptible to invasion by extracorporeal organisms than bodies that were buried with their skin intact (Janaway 1996). There have been two recent studies in Canada (Calce and Rogers 2007) and in Britain (Cross and Simmons 2010) that have examined the impact of trauma on decomposition. The study by Calce and Rogers (2007) examined blunt force trauma, but more in relation to the confusion between trauma and other natural taphonomic changes which impact the body as opposed to the rate of decomposition. The study by Cross and Simmons (2010) found that areas of ballistic trauma were not preferentially selected for insect ovipositing and that decomposition was no different between groups of pigs with or without ballistic penetrative trauma.

The results of the experimental studies using animal proxies (Burger 1965; Cross and Simmons 2010 and Calce and Rogers 2007) have found that insects are not attracted to trauma sites, nor is decomposition accelerated in these areas. The impact of trauma on the overall acceleration of decomposition found by Mant (1987) may not be the result of tissue damage. The extent of blood loss as a variable in decomposition has not been previously investigated by any taphonomic study published in the literature.

The impact of these results indicate that blood loss as opposed to tissue trauma has been identified as a potentially significant predictive variable for decomposition in almost all scene types in the Canadian dataset. This will assist death investigators with the knowledge that extreme blood loss will contribute to the deceleration of decomposition and possibly an increase period of tissue preservation. As this is a newly identified variable, and one which is potentially significant, further research is needed to replicate these results and perhaps investigate the biological mechanism that blood loss has on the processes of decomposition.

The Impact of Drugs on Decomposition

There have been no studies published in the taphonomic literature which have examined the influence of drugs on the rate of human or animal proxy decomposition. Due the diversity and combination of drugs consumed by decedents in the study, it was not possible to examine the impact of a specific drugs or drug types like anti-depressants or antibiotics. Many of the individuals taking prescription drugs took a complex of drugs, making the isolation of a specific drug or type of drug difficult. This study compared the progression of decomposition for the groups of cases who were known to have consumed illicit drugs or prescription drugs in relation to those cases without drug use.

The mean ADD scores were examined for the stages of decomposition by drug use (Table 4.27). Comparison of the mean ADD scores were conducted using *t*-tests for groups with and without illicit and prescription drugs with negative results. The P-values calculated for the comparisons did not identify any statistically significant differences in the mean ADD scores for any of the groups. Drug use was evaluated as part of the multivariate analysis and was not identified as a contributing variable for decomposition in any of the scene type (Table 4.33).

The study examined the correlation between drug use and manner of death. It was found that illicit drug use was considerably more frequent with victims of homicides and accidents compared to suicides (Figure 4.103). A total of 48% of the homicide group had presence of illicit drugs versus 12% prescription drugs and 55% presence of alcohol. In the suicide group, the presence of illicit drugs was much lower at 9% while the prescription drugs was higher at 49%. In comparison, alcohol consumption was twice as frequent with homicide victims compared to suicide victims. The presence of alcohol in the suicide group was lower at only 25% compared to the homicide group (Figure 4.105). A comparison of the mean ADD scores for the groups of cases with and without drug use did not produce quantifiable or statistically significant differences (Table 4.27).

A study was conducted on bodies recovered over a three year period from the water ways of New York, New York (Lucas et al., 2002). The purpose of the study was to examine the toxicology results for the 123 deaths to determine whether or not there was a correlation between toxicology and manner of death. They found that ethanol and illicit drugs were detected in 53% of the group determined to have died by accident and 41% of the suicidal group. They determined that drug and alcohol abuse was not a reliable criterion to distinguish suicide from accident. There were no observations regarding homicides due to the small sample size (4%) in the study (*ibid*).

The Impact of Alcohol on Decomposition

The impact of alcohol in the body at the time of death is a variable which has not been previously investigated. The investigation of the impact of alcohol on decomposition using animal proxies is not appropriate due to ethical issues, and the information regarding alcohol consumption for donated or unidentified bodies at ARF or other similar facilities is not generally available. This study has provided the first opportunity to evaluate the potential impact of alcohol on the progression of human decomposition.

Within the dataset, 27% of the cases were known to have consumed alcohol prior to death, compared to 62% who were known not to have consumed alcohol. For the remaining 11%, there was insufficient information to determine whether there was or was not alcohol consumption (Figure 4.104). Alcohol consumption was recorded more frequently with homicide victims compared to suicide victims, which was unexpected (Figure 4.105). However, this may be the result of a larger sample of homicide as opposed to suicide cases in the dataset.

A comparison was conduction of the progression of decomposition in PMI days and ADD scores between the groups with and without alcohol use. Alcohol use appeared to have a differential impact on the advancement of decomposition. The comparison of mean ADD scores for each stage of decomposition demonstrated a slower rate of autolysis (x 2 slower) for the alcohol group, and a much faster rate for the onset of putrefaction in stages 3 and 4 (x 3.5 faster) compared to the group without alcohol use (Figure 4.108). This alcohol group also demonstrated a subsequent reduction in the rate of late stage decomposition compared to the group without alcohol use.

An examination of the regression slope between the ADD score and the decomposition score for cases with and without alcohol was conducted (Figure 4.106).

The frequency of RLDV (Figure 4.109) by alcohol was also conducted. Both of these separate analyses resulted in a quantifiable difference in the rate of decomposition between the groups with and those without alcohol consumption. The multivariate analysis identified alcohol consumption as a predictive variable for decomposition outdoors with a P-value of 0.027 (Table 4.28). Alcohol was identified as a significant variable in decomposition for the total dataset (Table 4.33).

Alcohol has an overall negative relationship with the progression of decomposition. The cases with alcohol use demonstrated a slower rate of autolysis, but acceleration through the onset and full development of putrefaction. Cases with alcohol lingered for a longer period of time in the stages of liquefaction and skeletonization which resulted in a longer PMI for total decomposition compared to the group without alcohol consumption. Alcohol (ethanol and butanol) is a bi-product of the process of bacterial carbohydrate fermentation (putrefaction) (Gill-King 1997). However, it is not known what effect the introduction of ethanol has on the biochemical processes of decomposition; however, the results appear to cause a deceleration in overall decomposition rates.

The significance of these results is that for the first time, alcohol has been identified as a potentially important variable affecting the progression of human decomposition. The presence of alcohol in the body appears to impact autolysis and putrefaction differently. Any attempt to predict the general post mortem interval of a victim must take into consideration alcohol consumption which may impact the relative rate of decomposition. Alcohol use had an overall negative or inhibitory affect on the rate of decomposition for the cases examined in this study.

5.2.6. ***The Complex of Variables Affecting Decomposition by Scene Type***

Regression analysis is a method that has been used by a number of decomposition studies examining the contribution of specific variables to the progression of decomposition (Fitzgerald & Oxenham 2009, Heaton et al., 2009, Simmons et al., 2010). The study by Megyesi et al. (2005) was one of the first to convert the stage of decomposition into quantitative data and assign it to an interval scale which provided the opportunity to evaluate other quantitative variables (such as temperature) on the progression of decomposition. There are few published studies which have used multivariate analysis to examine the contribution of a complex of variables on the progression of decomposition.

Multiple regression analysis was conducted to examine the contribution of all quantitative variables in this study affecting decomposition in all scene types. The analysis of variables affecting decomposition outside identified seven variables which account for 83% of the variability in decomposition (Table 4.28). This model identified the accumulation of time (PMI in days), precipitation and body size as having a positive impact on the progression of decomposition outside. The extent of insects and scavenging were also identified as significant predictive variables, however these variables only affected 14% of the cases in this study. The extents of blood loss and alcohol consumption were determined to have a significant and negative impact on the progression of decomposition outdoors. At 83% this model has a relatively high level of potential to predict the level of decomposition for a body outside given these seven variables.

The analysis of variables in the other three scene types did not produce models with equally high levels of predictive potential. The small sample sizes for the water and burial environments contributed to results of only 50% and 54% of the variability in decomposition being explained by the small number of identified variables (Tables 4.30 and 31). The variables which were identified as being significant in water were time and the level of submersion of the body. The deeper the level of submersion, the more it negatively impacted the decomposition score. For burial scenes, time (PMI in days), clothing and blood loss were the only contributing variables. Blood loss and clothing had a negative impact on decomposition for burials. For all cases regardless of scene type, time, insects, alcohol and blood loss were the four variables which contributed to 61% of the variability in the decomposition score (Table 4.32).

The model for the indoor scene produced the lowest level of predictability with slightly less than 50% (Table 4.29). Temperature, insects and blood loss were identified as significant predictive variables. The indoor scene type is the largest dataset in the study. It is proposed that the failure to produce a predictive model for the indoor dataset is due to the absence of information relating to the recorded levels of humidity. For the outdoor cases, the level of precipitation has been quantified and contributes to an appreciation of the level of humidity. Precipitation and therefore humidity variability has contributed to a more effective predictive model for the outdoor cases. There is no available information relating to humidity for the indoor cases. It is proposed that humidity is one of the principle predictive variables for the development of epidermal bullae and the desiccation and mummification of soft tissues indoors. It is also proposed that the quantification of humidity levels could contribute significantly to our understanding of decomposition and perhaps to the creation of a predictive model for decomposition indoors.

The multivariate analysis for indoor scenes identified only three variables which had a statistically significant impact on the progression of decomposition. These three variables were temperature, insect involvement and extent of blood loss. It is important to remember that only 7% of the indoor cases exhibited any kind of visible insect involvement, but for those 13 cases, insect activity did have a positive impact on the rate of decomposition. For the majority of the other cases, only blood loss and temperature were identified as predictive variables. The greater the extent of blood loss, the more it negatively impacted decomposition. The inside environment was the only scene type which identified temperature over time as a dependant variable. However the temperature used to calculate the ADD score for indoor scenes was an arbitrary daily temperature of 20 degrees Celsius. In this instance, there is no difference between the PMI and the ADD score as a predictive variable for decomposition indoors. The combination of these three variables represented $R^2(adj)=49.6\%$ of the variability in the decomposition score. This study has not accounted for all the variables which contribute to the majority of the progression of decomposition indoors.

This study has quantified a range of variables and used multivariate regression analysis to identify variables not previously identified as predictive variables to the progression of human decomposition. This is the first study to identify levels of blood loss and presence of alcohol as potentially significant predictive variables for decomposition. The impact of the results is to hopefully illustrate the advantages of a more holistic approach to decomposition studies and to better understand the cause of differing decomposition trajectories.

5.3. Part III: Ecozones as a Variable of Human Decomposition in Canada

One of the research goals of this project was to determine if there were quantifiable differences in the time or temperature it took a body to progress along the stages of decomposition by ecozone, regardless of scene type or season. The other question was whether alternate state of decomposition such as external moulding or mummification was limited to a specific region in Canada.

5.3.1. *Distribution of RLDV across Canada*

The majority of the cases in this study occurred in British Columbia; the Pacific Maritime ecozone (13), or in Ontario; the MixedWood Plain ecozone (8) (Figures 4.110, 4.111 & 4.112). There are however cases representing ecozones across Canada (Figure 4.111). There is a tremendous ecological diversity within Canada which has been represented by the cases in the six other ecozones of: Atlantic, Boreal shield, Mountain Cordillera, Prairie, Boreal Cordillera, and Boreal Plains. The ecozone is an attempt to individualize a geographical location with diagnostic flora, fauna or environmental characteristics. However, as the ecozone is the largest unit of division, there is still considerable ecological or environmental variability within each ecozone.

Galloway et al. (1989) attempted to create a baseline understating of decomposition in arid environments in the United States. It may have been possible to focus on a specific type of environment in that situation due to the availability of other retrospective studies describing decomposition in other geographical locations or environmental regions (Bass 1997; Rhine & Dawson 1998). In Canada, very little is known about baseline decomposition in most environment. It is necessary to gain a basic understanding of the general stages, and ranges within those stages of decomposition on a very high level of examination, before an attempt is made to differentiate decomposition in specific types of environments or regions within Canada.

The RLDV for each case was mapped to the nearest town or city level across Canada. The distribution of negative and positive RLDV cases was examined to determine if whether there was a geographical basis for the concentration of slower or faster rates of decomposition (Figure. 4.113). The map revealed a relatively even distribution of faster and slower cases across Canada. There was no specific location with a concentration of negative or positive RLDVs. These results may be reflective of reality, that the factors which affect the relative rate of decomposition are not the result of geographical location or environment alone. It is likely that the rate of decomposition is dictated by the immediate environmental, contextual or intrinsic variables of a body at a death scene.

The mean RLDVs were calculated for all cases within each of the 8 ecozones, outside and inside, to determine whether the mean RLDV were similar within the ecozone (Figures 4.114 & 4.115). A comparison of these mean scores did not demonstrate a consistency in generally positive or negative values for a specific ecozone for both inside and outside scene types within that ecozone. This might suggest that the variability in the rate of decomposition for cases within and between the ecozone is likely due to a complex of variable as opposed to ecozone alone. Although the RLDV has demonstrated its ability to identifying dissimilarities in the rate of decomposition based on variables such as alcohol consumption or age (Figure 4.109); the RLDV could not identify geospatial clusters based on the diversity between Canadian ecozones. It is likely that there are differences in the progression of decomposition between the ecozones. It would be necessary to construct a much larger dataset to compare decomposition between all the ecozones, or focus on two specific ecozones with sufficient sample sizes to permit a reasonable comparison.

Comparison of Mean ADD scores and PMI Days between Two Ecozones

The sample sizes were sufficient to conduct comparisons between the two main ecozones of MixedWood Plain (8) and the Pacific Maritime (13). The frequency of cases within these two ecozones is based on population concentrations within Canada. These two ecozones contain more than half of the total population of Canada; including urban centers such as Vancouver and Greater Vancouver, Ottawa, Montreal, Toronto and the Greater Toronto region.

The mean ADD scores and PMI days were compared for each stage of decomposition for ecozone 8 (MixedWood Plain) and 13 (Pacific Maritime) (Figures 4.116 and 4.117). The comparison did produce a quantifiable difference in the mean PMI days for many of the stages of decomposition between both ecozones. Ecozone 8 demonstrated a consistently faster rate of decomposition for almost all stages of decomposition compared to ecozone 13 (Figure 4.116). A comparison of the mean ADD scores produced inconclusive results with ecozone 13 showing a faster rate of decomposition in relation to temperature for stages 0 and 1. For stages 2 and 5, the results were variable (Figure 117), with no ecozone showing consistently slower or faster rates of decomposition. The inconsistent results for the ADD score may be the result of issues with the calculation of the ADD scores based on inaccurate temperatures for the scene and the failure to take into consideration negative temperatures.

Based on the predictive variable of time (PMI in days); there is a quantitative difference in the rate of decomposition between the two main ecozones within this study. The differences may be the result of overall temperature or humidity levels. The average temperatures for the Pacific Maritime ecozone are 12 – 18 degrees Celsius in the summer and 4 to 6 degrees Celsius in the winter. For the MixedWood Plains ecozone the average summer temperatures are 18 to 22 degrees Celsius and -3 to -12 degrees Celsius in the winter. The precipitation levels can range within both ecozones, however areas within the Pacific Maritime ecozone can experience more than 4000 mm of rain per annum compared to 720 – 1000 mm in the MixedWood Plains ecozone. The faster rate of decomposition in the MixedWood Plains ecozone compared to the Pacific Maritime ecozone may be the result of higher humidity levels as opposed to precipitation.

Southeast Ontario is well known for high ‘Humidex’ ratings in the summer due to warm air pushing north from the Gulf of Mexico. The Humidex is calculated using both the temperature and humidity levels to create a single value intended to indicate the expected comfort level for an individual with that combination of temperature and humidity. The amount of water vapour that the air can hold increases with temperature. At zero degrees a volume of air could only hold a cup of water compared to 2 liters of water for that same volume of air at 33 degrees Celsius. Relative humidity is the percentage of water vapour that the air actually holds, compared to the amount it could hold for that temperature. Relative humidity is a statement of how saturated the air is for that temperature compared to how much water vapour it actually contains. 100% relative humidity would be found in a cloud or in fog for instance. It may be speculated that it is the combination of temperature and humidity that has the greatest impact on the progression of decomposition.

The results suggest that the progression of decomposition is not the result of temperature alone, but temperature in combination with humidity. Humidex decreases with increasing latitudes which may help explain the lack of correlation of temperature to the stages of decomposition in Canada. This may have contributed to higher levels of correlation between the ADD score and progression of decomposition found by Megysi et al. (2005) for cases in the lower latitudes of the United States. We may not be attributing the appropriate environmental variables when we correlate the ADD score to the level of decomposition. It may be that humidity levels in combination with temperatures (a type of Humidex) have the largest impact on human decomposition. It is possible therefore that the higher humidity levels associated to the higher summer temperatures in the MixedWood Plains ecozone which is responsible for the acceleration of decomposition.

5.3.2. ***Distribution of Alternate States of Decomposition across Canada***

The geographical distribution of alternate states of decomposition such as moulding and mummification was examined using GIS. All of the cases with occurrences of external moulding were located in British Columbia (Figure 4.118). There was a very small representation of external moulding in the dataset. It is entirely likely that external moulding is not limited to the province of British Columbia. The results seem to suggest that moulding is triggered by moist, dark, and generally cool environments. The external colonization of algae or mould may also be due to the presence of this flora within the ecozones of British Columbia (Figure 4.119). The distribution of mummification was not associated to a specific geographic location or ecological zone (Figure 4.120). Mummification and adipocere formation are triggered by the specific immediate conditions of the body which include humidity, moisture, temperature or oxygen levels as opposed to variability in the geographical and ecological location.

Geographic or ecological variability as it affects decomposition has been investigated by multiple forensic taphonomy researchers. Galloway et al. (1989) noticed in Arizona that increased altitude appeared to slow the rates of decomposition at a State level. Prieto et al.'s (2004) study in Spain did not find regional difference between coastal and interior environments. It is interesting however that any variability in the progression of decomposition in Spain was attributed to diversity in humidity levels (Prieto et al., 2004).

Although Geographic Information Systems (GIS) and spatial analysis has been used before in forensic taphonomy studies (Manhein et al., 2006), the focus of these types of studies was the geospatial patterning of dumped bodies or deposition of bodies by tides or river flow. The study conducted by Manhein et al. (2006), examined the distribution of dumped bodies and scattered remains to identify any geospatial patterns for the development of search and recovery methodologies. Unfortunately, the study did not identify consistent patterns in either the location of the dumps or distribution of the scatter. GIS has not been used to identify regional patterns of alternate states of decomposition or the distribution of cases with slower or faster rates of decomposition.

The comparison of mean PMI days for stages of decomposition did identify a quantifiable difference in the rate of decomposition between ecozone 8 and 13; two very different ecozones in Canada. The faster rate of decomposition in ecozone 8 may be result of higher humidity levels associated to higher temperature levels during the summer. The RLDV did not identify any clusters of cases with consistently faster or slower decomposition based on geography or ecozones. The result suggests that the diversity in the rates of decomposition was the result of a complex of environmental, immediate context and intrinsic variables rather than geography/ecology alone. The distribution of alternate states of decomposition did associate external moulding to British Columbia, the small sample sizes of this type of alternate state of decomposition does not preclude it from occurring in other places in Canada. The results suggest the development of moulding is the result of low levels of sunlight, temperatures, and humidity with the availability of particular types of algae or fungi in that ecological environment.

5.4. Part IV: The Calculation of PMI Estimations in Canada

The aims of this section were to test the two so-called “Universal Formulas” proposed by Vass (2011) to calculate accurate and useful PMI estimations for cases above and below the ground using the cases in this study. The second aim of this part of the study was to determine whether or not it is possible to estimate accurate and forensically useful PMI estimations based on the variability within the biological processes of decomposition and the variability in decomposition between scene types and ecozones.

Vass (2011) has proposed that two formulas could be applied globally to produce “rapid and fairly accurate” (Ibid: 35) PMI estimations as a ‘rule of thumb’ for investigators. Formula 1 was designed to calculate the PMI for bodies above ground. There were two main constants proposed with this formula: that soft tissue decomposition ceased at 1285 ADD and that the effect of moisture could be calculated using a constant factor of 0.0103. It would appear that soft tissue decomposition does not cease at an accumulation of 1285 ADD as there are 10 cases in this dataset with ongoing colliquation well past the 1285 ADD score.

The constant factor of 0.0103 for moisture in Formula 1 was tested using a set of 10 cases randomly selected cases from a set of 50 acceptable outdoor cases. What constituted an acceptable case for the application of this formula was dictated by the parameters stated in Vass (2011). Specifically, these cases were required to have more than one day PMI, no adipocere formation, no exposure to cold temperatures, outside on the surface, and alteration to the body by scavengers. The temperature, humidity and decomposition data from these 10 cases was used to calculate a PMI estimate using Formula 1. These PMI estimation results were compared to the actual know PMIs for each case. The PMI estimations produced by Formula 1 were remarkably inaccurate with an overestimation of up to 30 times the actual PMI (Table 4.34). It would appear that the maximum ADD calculation for soft tissue decomposition and the constant factor of 0.0103 for the contribution of moisture does not apply universally. It is interesting to note that Vass (2011) did not attempt to validate this formula with any cases from the Knoxville Tennessee area. Any PMI calculated using this formula would certainly produce a dramatically over-estimated and misleading PMI for cases in Canada.

In the second formula (II) proposed by Vass (2011) to estimate the PMI for buried bodies, a premise of 4.6 is used for the ratio of deceleration for buried compared to surface decomposition. The validity of this premise was tested using the buried and surface cases from this study. For three stages of decomposition (stages 0, 1 and 7) the progression of decomposition was actually faster for buried versus surface cases (Table 4.35). The average PMI (in days) ratio for putrefaction (stages 3 – 5) was 5.36 times slower in a burial compared to the surface. In relation to the ADD score however, the average ratio difference is 87 times slower for buried compared to surface cases. The constant value of 4.6 for the deceleration in the rate of decomposition for buried versus surface decomposition cannot be validated by the buried cases in this study. It was not possible to test the accuracy of Formula II as data relating to ground temperature and humidity levels were required for the calculation. In fact, it is unlikely that Formula II could be successfully utilized for Canadian cases since the Formula uses the erroneous constants of 1285 ADD for the end of soft tissue decomposition and the factor of 4.6 for the deceleration ratio of buried compared to surface bodies. In other words, Formula I invalidates Formula II.

Vass did test Formula II using three buried cases, presumably from the Knoxville, Tennessee area; Vass produced estimations for three cases with relatively long PMIs. His PMI estimations were as follows: 23 months (actual 22 months), 18.2 years (actual 18 years), and 5.4 to 6.5 years (actual 8 years). For two of his test cases the PMI estimates were within a few months of the actual PMI, however the estimate for the last cases was in error by 2.6 to 1.5 years. Due to the failure to validate the ratio's used by Formula II for the buried versus surface cases in Canada, it is not hopeful that accurate PMIs could be calculated for Canadian cases using this methodology. The results of the validation study conducted by Vass (2011) using three cases from the Knoxville Tennessee area do not offer much hope that accurate and useful PMI estimations could be calculated for that region either. In conclusion, the findings are that the formulas proposed by Vass's (2011) cannot be accurately applied to this Canadian dataset.

5.4.1. ***PMI Estimations Based on the Study Dataset***

The aim of this section was to review the results of this study to determine whether the progression of baseline decomposition, and the differences in the progression of decomposition between regions and contexts, occurred with sufficient predictability to facilitate accurate and forensically useful PMI estimations.

Baseline Progression of Decomposition: Part I

The results of this study have demonstrated that there is an exponential increase in the variability associated to the progression of decomposition. For all scene types, the variability increases dramatically during the stages of putrefaction. The time range charts for the burial and water scenes (Figure 4.13 buried & Figure 4.36 water) show the range in variability for a specific stage of decomposition and demonstrated a definite increase in the unpredictability of putrefaction between stages 3 and 5. This same pattern of unpredictability is reiterated by the results for the indoor and outdoor datasets. The time progressions (Figure 4.31 Indoor; Figure 4.15 outdoor) for indoor and outdoor decomposition clearly indicate the marked onset of variability at stage 5. These results suggest that a body, regardless of scene type, may linger in the later stages of putrefaction (stage 5) for an indeterminate period of time. The time or temperatures needed to progress through putrefaction towards skeletonization is unpredictable in any context.

If the time or temperature progression of putrefaction cannot be projected, would it be possible to predict the advancement of autolysis based on the results of this study? If so, would those predictions be sufficiently restricted to make them useful to the medico-legal community? The two largest sets of cases from the outside and inside scene types have been used to answer these questions. Although the mean scores have been provided to quantify the PMI in days or ADD score for each stage of decomposition by scene type, it is the confidence intervals associated to those mean scores which are important to evaluate the predictive value of the calculation.

The total confidence interval range was calculated for each stage of decomposition by scene type to illustrate the predictive value of that stage for possible PMI estimations (Table 4.36). For outdoor scene types, the total confidence intervals for autolysis were: stage 0= 3.1 days; stage 1=5.1 days; stage 2=37.4 days. These numbers describe the absolute range in days on either side of the mean calculation. Therefore a PMI estimate for stage 1 outside could be anywhere between 7 to 1.5 days (based on a mean of 4.1 days). For the indoor dataset, the confidence interval ranges are smaller which suggests a higher level of confidence for PMI estimations. The total confidence intervals for autolysis indoors were: stage 0= 1.7 days; stage 1=0.5 days; stage 2=2.5 days. The PMI estimate for stage 1 decomposition indoor would therefore be anywhere from 1.9 to 2.4 days. However the PMI time range for stage 2 inside would be anywhere from 2 to 4.5 days (based on a mean of 3.2 days). These types of PMI estimates may prove useful for information gathering purposes, however it would not be possible, even in the early stages of decomposition inside, to provide a sufficiently restricted PMI estimation to counter or confirm alibis to the hour or the day.

Trend analysis was used for the indoor and outdoor progression of decomposition to gauge the potential to predict the PMI for later stages of decomposition based on earlier stages (Figures 4.121, 122 and 123). The trend which fitted both indoor and outdoor datasets was the exponential growth model. This pattern or exponential growth for confidence intervals confirms the lack of a linear progression of decomposition and associated predictability. As the stages of decomposition increase, the error rates increase exponentially. Any PMI estimates for the late stages of putrefaction and skeletonization would have such a considerable error rate as to render it useless for the law enforcement community.

The data therefore suggests that although there may be smaller error rates associated to the early stages of decomposition inside, the error rate increases exponentially with the stages of decomposition. For the discovered bodies in the early stages of decomposition, their facial features may still be recognizable and therefore positive identification possible through conventional means. It is the human remains found in the later stages of decomposition which pose the greatest problem for death investigators as identification must be determined through fingerprints, dental records, or as a very last resort – DNA. It is these types of cases that death investigators request the assistance of forensic anthropologists to establish the PMI; however it is exactly these types of cases which exhibit the largest variability in the inherent progression of ongoing putrefaction and skeletonization. It may be tempting for a forensic anthropologist to provide a ‘ball park’ PMI for death investigators, however based on the inherent variability in the later stages of baseline decomposition in any context, they should very much resist that urge.

The Variables which Affect Decomposition: Part II

Has this study identified the range of variables which contribute to the majority of the variability in the progression of decomposition? The answer to this question varies depending on scene type. If the critical predictive variables have been identified, it may be possible to create a predictive model for a scene type which could be tested for reliability with a separate set of known cases.

It has been demonstrated that the ADD score alone is insufficient as an independent variable to predict the stage of decomposition for human remains. The reasons for this may be due to a large error rate in the temperature recorded from the nearest weather station and the actual death scene (Fitzgerald & Oxenham 2009). It may also be due to climactic differences between the study area used by Megyesi et al. (2005) and this study. The majority of the cases used by Megyesi et al. were from Indiana and Illinois, however 17 other states were represented (2005:2). These cases were likely exposed to warmer and more humid environmental conditions compared to the Canadian cases. The Canadian cases were also exposed to cold and freezing temperatures during the winter. As has been previously discussed, the method of ADD score calculation by Megyesi et.al. (2005) did not take into consideration these sub-zero temperatures, which has been demonstrated to have a quantifiable impact on the progression of decomposition.

The investigation into the variables which affect decomposition outside on the surface produced the best results, which is interesting as it is one of the scene types which are subject to a large range of environmental and contextual variables. A total of seven variables were identified as being predictive for the outside surface context: Time (PMI in days); precipitation; scavenging; insects; alcohol; build and blood loss. All variables apart from alcohol and blood loss had a positive impact on the progression of decomposition. Alcohol and blood loss had a negative impact on decomposition in that context. These seven variables explain 83% of the change in the decomposition score. However, for found remains, all of the six variables would be needed to provide an estimate of the PMI; including the PMI. Although this study has identified which variables contributed to the majority of the change in decomposition outdoors, it has not identified which range of variables, available from the scene or body, which would generate a PMI.

It is almost counterintuitive that the most controlled and protected scene types had the least successful results for the identification of variables which affect decomposition inside. The three variables of time temperature (ADD score), insect involvement and blood loss accounted for only 49.6% of the change in the progression of decomposition inside. Only 7% of the inside cases had any sign of insect involvement, so for the majority of the cases, the level of blood loss and the ADD score were the only two contributing variables to decomposition. The reasons for this is likely due to the absence of information on a critical predictive variable; humidity. The level of atmospheric humidity is at least suggested to a certain extent by the amount of accumulated precipitation for a scene outdoors, however that information is missing entirely for indoor scenes. Although the indoor scenes demonstrate the highest potential for predictability given the trend analysis, without the data related to atmospheric humidity in combination with temperature, we are still unable to predict the PMI for indoor scenes in Canada.

The identification of predictive variables for the last two scene types have been restricted by the smallest sample sizes. The burial and water scenes with 22 and 27 cases respectively, did not produce much better results than the indoor dataset with the largest sample size (193 cases). In water, the two variables of time and level of submersion, which has a negative impact on decomposition, was responsible for only 53.2% of the change in the decomposition score. For the burial scenes, three variables were identified as being predictive; time (PMI in days), blood loss and level of clothing. Both level of clothing and blood loss had a negative impact on the progression of decomposing in burials. These three variables only contributed to 50.2% of the change in the decomposition score in burials. For these two scene types, even allowing for the small sample size, the study has not identified the critical variables which affect decomposition in these types of environments. Water and soil temperature and soil humidity may well be the critical predictive variables for these environments which were not available to this retrospective study.

One of the benefits of this study is that many of the variables which were suspected to have a significant impact on decomposition may not be as important as previously thought. As the result of this study perhaps less emphasis can be placed on variables such as sun exposure, clothing (except in burials), burial depth, sex, and manner of death in future experimental designs for taphonomic research in Canada. Variables not previously identified and worthy of future investigation include age, blood loss and alcohol consumption. The two variables of insect and scavenger involvement do have an impact on decomposition, but their occurrence at death scenes in Canada is relatively infrequent, unpredictable and indiscriminate in nature. Although progress has been made towards a better understanding of human decomposition, it is still not possible to produce reliable and accurate PMI estimations based on the visible state of the body in Canada.

Regional Variability of Human Decomposition in Canada: Part III

For PMI estimations to have a certain level of utility for the forensic community, a methodology should be applicable on a national or regional scale. Is there sufficient commonality in the progression of decomposition between two populace ecozones such as the MixedWood Plain and Pacific Maritime to construct common schedules for baseline decomposition? The correlation of the ADD score and PMI days to the stages in decomposition between the MixedWood Plain (8) and Pacific Maritime (13) ecozones demonstrated that ecozone 8 had a consistently faster rate of decomposition in the earlier stages (autolysis - 0, 1, 2) of decomposition. There was a difference in the regional distribution of alternate states of decomposition. Cases with wet moulding were only located in British Columbia and generally associated with darker, cooler moist environments. Although the difference in the rate of decomposition between these two ecozones is not statistically significant, the differences are large enough to negatively impact any PMI estimations.

There are considerable environmental, ecological and climactic differences between these two ecozone which could contribute to the differences in the rate of decomposition. The main two environmental variables of temperature and precipitation have been calculated and are not entirely responsible for the variability. Some researchers believe that variables such as the temperature, type or pH of the substrate or context may be important; others believe that the geology, local faunal complexities or meteorology are important predictors of decomposition (Table 2.7). The quantification of these types of variables, including temperature and humidity should be conducted at a crime scene with human remains to determine their level of impact on decomposition. Before animals such as pigs are used as a proxy for humans, experimentation is needed to establish the similarities and disparities in decomposition between both species. As it stands now, there is no published basis for comparison between the decomposition of pigs and humans.

In summary, there are quantifiable differences in the progression of decomposition between the four scene types and the two largest ecozones represented in this study. There is an exponential increase in the variability of baseline decomposition with the progression of decomposition. The time or temperature a body takes to progress past the end state of putrefaction towards skeletonization is highly variable. A PMI estimate for a body in late stage putrefaction in any context would have an error rate so large as to make it useless for investigative purposes. Currently we do not have comprehensive understanding of all the variables which impact the progression of decomposition in a range of scene types. A regional dataset would need to be generated for each major ecozone to generate reliable PMI estimates with an established error rate. Without knowing exactly what it is about the geographic location which specifically impacts decomposition, it is difficult to know how expansive or inclusive a regional model would need to be to be in order to be accurate and reliable.

This study has demonstrated how little we know about the complexity of variables which affect decomposition. The quick fixes of cumulative temperature (ADD score) cannot be used in Canada to account for the majority of change in the decomposition score. A body decomposes at a different rate with visibly different states depending on context or ecozone. There is an inherent unpredictability with the time and temperature a body lingers in the later stages of decomposition. The combination of these issues, with the failure of the ‘universal formulas’ (Vass 2011) support the belief that PMI estimations based on the visible state of the body, are not only unreliable, but practically irresponsible given the current state of our knowledge of human decomposition.

5.5. Study Limitations

There are several limitations associated to this type of retrospective study. The most significant limitation is that the investigator is afforded only a synchronic perspective of decomposition at the point of discovery. It is unknown how long the body may have lingered in that particular stage of decomposition before discovery, therefore the classification of the stage of decomposition becomes a maximum estimate. The advantage of the other two methodologies of human or animal proxy experimentation is that the researchers can record the diachronic progression of decomposition over time and record the timing of the transition from one stage to the next. It is also possible for the experimental researcher to record information specific to the scene such as soil temperature, pH, elevation or humidity. Only the data collected by the crime scene investigators and pathologists are available during a retrospective study. It is hoped that as a result of this study, other information relevant to taphonomic research can be collected during the scene attendance by death investigators. This added information, such as humidity and temperature or soil moisture and temperature for burials, could improve the limitations of retrospective studies for future research.

The environmental data used for this study was arbitrarily assigned or taken from the closest weather station and may not accurately reflect the environmental conditions at that specific scene. It is also hoped that with future research the difference between the temperature recorded at the scene and the closest weather station can be measured to create an error factor to compensate for the disparity between the environmental data recorded at the scene and the nearest weather station.

Whenever a source of data is mined for information not necessarily related to the original function of the data, there may be limitations. As the result of the complexity of human decomposition, there may be many more variables not identified by this study which have an impact on the progression of decomposition. Due to logistical and jurisdictional issues, not all geographical regions are equally represented in this study. The population densities for this retrospective study were concentrated in the Greater Vancouver, British Columbia and Ottawa, Ontario regions. Due to population densities and discovery rates, there are proportionately more cases in this study discovered in an earlier stage of decomposition compared to later stages. With better access to Provincial

Coroner, Medical Examiner or police files, it is hoped that future retrospective studies can create larger dataset with cases representing all regions across Canada which would provide a more representative perspective of human decomposition for all regions of Canada.

6. Conclusions

There is a scarcity of research focusing on the visible progression of human decomposition in Canada. The only retrospective study examining decomposition outside on the surface included two decomposed and scavenged cases recovered near Edmonton, Alberta. Forensic entomology studies in British Columbia included a total of 42 human cases but provided limited information relating to the visible progression of decomposition in water. There is currently no description of the normal progression of human decomposition underground or within a structure in Canada. Retrospective studies conducted primarily in the United States are regionally and environmentally specific with limited application to decomposition in Canada. There has been a plethora of animal proxy experiments conducted with a focus on forensic entomology or decomposition chemistry in Canada. The results of these studies have advanced our understanding of insect succession and the processes relating to pig decomposition. Unfortunately, the correlation between pig and human decomposition has yet to be established.

The application of anthropological theory and methods to criminal investigations carries with it a level of risk to society. There is a responsibility on the part of the discipline to ensure that those methods and theories used to create expert opinions in a court of law are objective and reliable. The Daubert Standard (1993) (Daubert v. Merrell Dow Pharmaceuticals) regarding the admissibility of expert evidence in the United States and the R v. Mohan [1994] ruling in Canada have established minimum standards for the reliability, repeatability and relevance of scientific opinions. Any science which ventures into the realm of forensics needs to comply with these standards. This study has endeavoured to ensure that the methods are explicit and that quantified results have been presented with an associated error rate. The value of any forensic anthropology opinion is based on the reliability of the method as opposed to the credentials or reputation of the expert.

The purpose of this study was to:

1. Describe and define baseline decomposition in the four scene types in Canada. Determine the presence and extent of the alternate states of decomposition in these four scene types.
2. Identify the variables which are responsible for the progression of decomposition in the four scene types.
3. Determine the geographical variability of decomposition and alternate states of decomposition in Canada.
4. Determine whether it might be possible to produce reliable and accurate PMI estimations for cases in Canada.

This retrospective study of human decomposition included 358 cases from across Canada. A maximum of 46 descriptors were recorded for each case, which produced up to 36 interval or nominal variables. These variables were examined individually and collectively to evaluate their impact on the progression of decomposition. A different set of variables were identified and examined for each of the four main scene types: outdoors on the surface, outdoor under the surface, in water and indoors.

To define the *normal* or baseline progression of decomposition in Canada, a classification system was created to describe and define the visible changes occurring to a body from death to skeletonization. The reliability of this classification system was confirmed with an inter-observer error study. The states of decomposition which are caused by specific environmental conditions were differentiated from baseline decomposition. These alternate states of decomposition included mummification, moulding and adipocere formation. It was observed that an alternate state of decomposition called epidermal bullae, was limited to the indoor context for cases within this study. The frequency and development of these alternate states of decomposition was described for each scene context. It is proposed that low humidity levels played a large role in the formation of epidermal bullae and mummification regardless of temperature. There was a complex of contextual and environmental variables which triggered the relatively rare occurrence of adipocere formation and moulding for cases in this study.

The results of this study have produced the quantitative progression of indoor, outdoor, water and buried baseline decomposition. It has been found that decomposition indoors occurs at a more rapid rate compared to decomposition outdoors. The burial and water data sets had the smallest sample size with 27 and 22 cases. The results of the quantitative analysis of the progression of decomposition demonstrated that water decomposition proceeded at the slowest rate, followed narrowly by burial decomposition. This slower rate of water decomposition may be the result of many of the bodies in this data set being exposed to freezing water temperatures.

The results have also demonstrated that the progression of decomposition does not occur at a constant rate. The stages of autolysis appear to proceed within relatively short and predictable time spans, however after the onset of putrefaction, (stage 5) there was a marked increase in the time or temperature duration of each successive stage of decomposition. The confidence intervals calculated for the average temperature (ADD Score) or time (PMI days) taken to achieve each stage of decomposition increased at an exponential rate during the stages of putrefaction and skeletonization. The size of these confidence intervals during the later stages of decomposition limits the usefulness of any PMI estimations using the quantitative results from this study regardless of scene type.

There are qualitative differences in the visible appearance of bodies decomposing in different scene contexts. These differences are more visibly apparent during the later stages of putrefaction and colliquation. Late stage decomposition outdoors was characterized by black desiccated tissue adhering to exposed bone. The later stages of burial decomposition were characterized by a moist brown tissue discolouration. Inside decomposition was defined by extensive tissue desiccation with or without epidermal bullae. Water decomposition was recognizable based on the presence of skin sloughing associated with reddish tissue discolouration. These findings have now established for the first time what *normal* decomposition should look like given a particular context.

All bodies given the optimal conditions progress through baseline decomposition. However specific conditions have to be present for a body to mummify, mould or covert adipose tissue into adipocere. This study observed that mummification outdoors occurred earlier in winter as opposed to summer, likely due to lower levels of humidity in winter. Mummification indoors progressed at a predictable rate with most indoor bodies stabilizing in a desiccated state without transiting towards full skeletonization regardless of the accumulation of time or temperature. The formation of epidermal bullae, was limited to indoor scenes in this dataset. Adipocere formation occurred infrequently, with onset recorded earlier in a burial as opposed to a water context. Dry moulding occurred infrequently and was generally limited to appendages and facial features in any scene context. Wet moulding was only recorded at scenes in British Columbia and appeared to be associated with bodies exposed to freezing temperatures, in wet, cool, dark environments.

The variables which impacted the progression of decomposition were defined as part two of the study. The progression of decomposition is generally measured by the progression of time (PMI in days), and more recently by the accumulation of temperature (ADD score). These two variables were evaluated to determine whether the accumulation of time or temperature contributed to more change in the progression of the decomposition score. Temperature (ADD score) was found to have a slightly higher predictive potential as an independent variable compared to time, however, when evaluated within a complex of variables, time (PMI in days) was found to have a more significant contribution to the progression of decomposition compared to the accumulation of temperature (ADD score).

Since 1995, there has been considerable optimism for the ADD score to be the principle predictive variable for decomposition. Most researchers appreciate that there is a complex of variables which affect decomposition, however recently they have been hoping that the ADD score could simplify that complexity and attribute all responsibility for the changes in decomposition to the accumulation of temperature. Unfortunately, the correlation results for the ADD score to decomposition in this study were extremely disappointing. A much higher level of correlation was found by Megyesi et al. (2005) at 85% with 66 cases, compared to 39% for 341 cases in this study. As the accumulation of temperature alone cannot be used to explain the progression of decomposition, environmental, contextual and intrinsic variables were examined to determine which of them, or which complex of them, affected change in the decomposition score.

The individual variables that were found to have a quantifiable impact on the progression of decomposition were age, alcohol consumption, extent of blood loss, shade and exposure to cold temperatures. The rate of decomposition was decelerated in babies, may be due to a limited frequency and complexity of gut flora. Alcohol consumption, cold exposure and blood loss all had a negative impact on the progression of decomposition. Decomposition was found to progress at a more rapid rate in the shade compared to the sun. The presence of shade did not correlate with more insect activity and a subsequent acceleration in decomposition. Although insect activity and scavenging were found to have a significant positive impact on decomposition, only 10% of the cases in this study were impacted by insects and 17% for scavenging in any context. The independent variables which did not have any measurable impact on the progression of decomposition for cases within this study were sex, build, extent of clothing or depth of burial. The results for variables such as extent and type of shroud and drug consumption were indeterminate due to the small sample sizes. Blood loss, alcohol consumption, and age are variables which have not been previously identified as contributing to decomposition by any other published study.

The complex of variables present at each scene was examined to determine which combination of variables would contribute to the majority of change in the decomposition score. The outdoor scene type had the largest number of variables. Seven of these variables were identified as contributing to 83% of the variability in the decomposition score outdoors. The accumulation of time (PMI in days) and precipitation, the impact of scavengers and insects, build (or body size), consumption of alcohol and extent of blood loss were found collectively to influence the progression of decomposition in an either negative or positive manner outside. The attempt to identify the complex of predictive variables for the three other scene types was not as successful. Indoors, the accumulation of temperature, insect activity and extent of blood loss was found to contribute to only 50% of the variability in the decomposition score. Only 7% of cases indoors exhibited any visible sign of insect activity and the accumulation of temperature (an arbitrary 20 ºC/day) had the same impact as the accumulation of time indoors. Only two variables were identified for the water scenes;

the passage of time and the level of submersion. These two variables contributed to 54% of the variability in water decomposition. Three variables were identified for the buried scenes: the passage of time, extent of blood loss and extent of clothing which contributed to 50% of the variability in decomposition in burials. It is clear that many of the variables which affect decomposition indoors, in burials and in water have not been identified. It is proposed that humidity is one of the most significant contributors to both baseline and alternate decomposition indoors. Soil and water temperature in combination with moisture levels for the burial environment are likely significant contributing variables.

The multivariate results were surprising, in that the one scene type with the most environmental and contextual variability produced the highest level of predictability. It could be proposed that the seven variables identified for the outdoor scenes could be used to create a predictive model to estimate the PMI for found human remains. However, the one critical variable of time must be known for that predictive model to work, which seems to defeat the purposes of a PMI estimation method. Given the circumstances and known time period for missing human remains, this data may assist investigators to estimate the predicted level of decomposition which would determine the search and recovery strategy.

There are regional differences in the rate and progression of decomposition between Ecozones in Canada. A comparison of decomposition between the Pacific Maritime (Vancouver region) and MixedWood Plains (Ottawa, Toronto, Montreal region) ecozones found that the MixedWood Plain had a faster rate of decomposition both indoors and outdoors for most stages of decomposition. The comparison of ADD scores between the two ecozones produced mixed results. The failure to identify differences based on the ADD score may be due to issues with the calculation of the ADD score. There is likely an error introduced by inaccurate environmental data taken from the closest weather station and a failure to take into consideration the negative impact of freezing temperatures during decomposition. This study has demonstrated that given two cases with the same ADD score, the one case which was exposed to cold or freezing temperatures will have a slower rate of decomposition. The only alternate state of decomposition which was determined to be geographically limited was wet moulding. The few cases of moulding on a wet substrate were limited to British Columbia; however this state of decomposition was likely triggered by cold or freezing temperatures in a moist dark environment, colonized by algae or fungi specific to that environment.

The only existing methodology proposed to estimate PMIs based on the visible state of the body was tested using the cases from this study. The two Universal Formulas proposed by Vass (2011) were intended for law enforcement use to estimate reliable and accurate PMIs for buried and surface bodies everywhere. Formula I (for surface decomposition) was tested using 10 cases from this study and found to overestimate the known PMI by as much as 30 times. The premises used by both formulas for decomposition above and below the surface were found to be invalid based on the results of this study. This study has established that the Universal formulas are not applicable to cases in Canada.

Without an existing reliable methodology to predict the PMI, the aim of this study was to evaluate whether it was feasible to create any method of PMI estimation considering the inherent variability within the process of decomposition and between scene types and regions. This study has demonstrated that there is considerable time and temperature variability in the biological progression of decomposition. This variability increases at an exponential rate with the increasing stages of decomposition. This unpredictability would produce PMI estimations with error rates so large as to make their use limited to a criminal investigation and a court of law. This study has also demonstrated that there is a quantifiable difference in the time it takes for each stage of decomposition between the two main ecozones and a considerable difference in the progression of decomposition between scene types. To create accurate and reliable PMI estimation models, it would be necessary to create regionally based sequences of baseline decomposition for each scene type. This would be extremely time consuming and impractical.

6.1. Implications and Future Research

The main contribution of this study was to provide an understanding of the baseline progression of decomposition outdoors, indoors, in burials and in water in Canada. This knowledge of what is *normal* will assist investigators to recognize whether a found body has been moved from its original context i.e., from indoors to outdoors. The ability to recognize the visible signs of burial decomposition for a body discovered on the surface would ensure that a search is conducted to locate the originating grave. The signs of indoor decomposition for a body located outdoors would also ensure that investigators search for the originating indoor context and probable death scene. The ability to recognize water decomposition for dried remains on a bank or beach will help answer the question whether the body originated from water or the land. Investigators will also be able to create search and recovery methods based on the expected level of decomposition given a set of circumstances for victims of accidents or crime outside on the surface, under the surface or in water.

As a result of this study, further research is needed to confirm the potential importance of the variables identified, as part of this study, as having a significant role in the progression of decomposition. Further research is needed to confirm the validity of the relative contribution of specific variables with another independent retrospective study involving another set of Canadian cases. Further research is also needed to confirm the assumption that humidity is an important predictive variable for baseline decomposition and the formation of alternate states of decomposition in multiple scene types. As a result of this the Standard Operating Guidelines (SOGs) will be modified to instruct RCMP Forensic Identification (FI) members attending death scenes to assess and record the predictive variables identified by this study for decomposition in that scene type. The FI members also be instructed to take temperature and humidity readings at all death scenes. This will enable further research to be conducted to understand the impact that all of these variables have on the progression decomposition at all death scenes across Canada.

With a better understanding of the variables which affect decomposition, the current Disaster Victim Identification (DVI) protocols used to manage the storage of victims of mass disasters will be amended. With the presumptive role of humidity during decomposition, the levels of humidity in addition to temperature will be reduces and the levels of light (specifically UV) increased to ensure the deceleration of colliquation and reduce the growth of wet and dry mould growth which poses a health and safety risk to morgue staff.

The quest for a reliable means to estimate the PMI for found remains has been a long one. This study has demonstrated that the current methods of PMI estimation are not accurate and that human decomposition is inherently variable and context dependant. The PMI estimations would be produced with required error rates so large as to make them impracticable for legal purposes. During the past 20 years however, advancements have been made in technology that have changed the needs of the modern criminal investigation. There are now reliable means of estimating PMI based on cell phone or bank card usage and increasingly, by CCTV footage. These methods, in combination with witness or suspect statements are currently being used to establish the perimortem interval for court purposes. There is no longer a need to establish an accurate and reliable time since death estimation based on the visible state of the found remains for court purposes. There is however a need to establish a time range since death for investigative purposes. This time range would assist investigators to limit the list of missing persons to identify the remains, and once identified, limit the time period to search phone, bank and CCTV records. This post mortem time range could be provided as an investigational tool as opposed to a medico- legal opinion for a court of law.

Further research within forensic taphonomy could focus on establishing the error rate inherent in the ADD score calculation and find a way to incorporate the negative impact of freezing temperatures. A study could be conducted to quantify the average difference between the environmental data recorded at the site and the data recorded at the nearest weather station. This study could also examine the variability in temperature and humidity within a specific geographical region based on aspect, vegetation cover or elevation. This would assist in establishing which variables affect the temperature and humidity ranges within the same region and determine the range of error, if any, between the readings taken at the site and those from the closest weather station used to calculate the ADD score.

It is proposed that further research could focus on determining the decompositional differences between humans and animal proxies. The qualitative and quantitative differences between proxy and human decomposition need to be established to facilitate the ongoing use of animal for experimental research. It is suggested that the decomposition results of future animal proxy studies conducted within the Pacific Maritime or MixedWood Plain ecozones could be compared to the baseline data produced by this study to establish the time or temperature differences for each of the stages of decomposition. There an obvious logistical need to continue with the use of animal proxies for taphonomic experimental studies, however the establishment of a quantified error rate is needed before the results from those studies can be directly applied to our understanding of human decomposition.

Overall, this study has made a large contribution to our understanding of human decomposition and the variables which affect it at death scene, not only in Canada, but in general. This study has addressed many assumptions regarding what variables do and do not affect decomposition and identified variables not previously considered. The results of this study have established that there is an inherent variability within the biological progression of decomposition and a level of ignorance relating to our understanding of all the variables which impact that progression. The variability of human decomposition makes any PMI estimation based on the visible state of decomposition impractical and forensically irresponsible based on our current level of knowledge.

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Appendices

Appendix A. The Inter-observer error study

Part 1. Tissue Decomposition Classification System

INSTRUCTIONAL INFORMATION

BASELINE DECOMPOSITION

AUTOLYSIS

Autolysis involves the action of enzymes. Due to the failure of biosynthesis, fermentation using lactic acids increases the acidity and activates hydrolytic enzymes which denatures the cell. The cells loose cohesion and release water. The breakdown of the cells also releases carbohydrates, proteins and fat which will later fuel putrefaction.

0. Shortly after death there will be no visible change yet. There is no colour change – body looks fresh.

1. A few hours after death, the first colour change occurs – no tissue change yet

a. **Liver mortis** – the pooling of blood to the dependant portions of the body (blanching where the tissue is in contact with a surface.

b. **Rigor mortis** – Stiffening of all tissues – which will release after a period of time

2. The first signs of tissue changes - the bond between the epidermis and dermis releases. fluids between the layers of skin creates skin slippage.

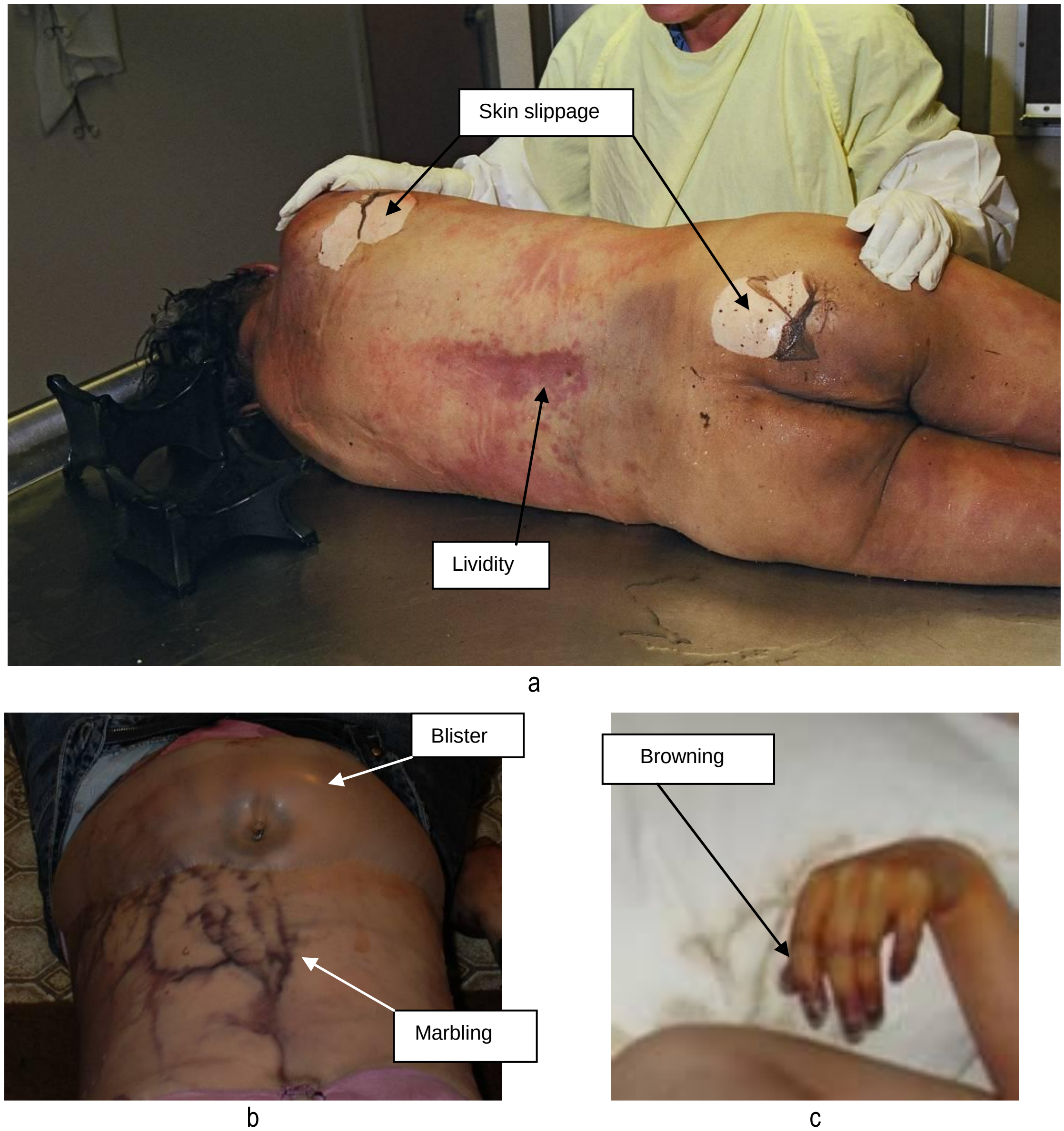


Figure 1. a: Skin slippage and liver mortis, b: blisters and marbling of blood in the veins, c: browning of exposed extremities due to desiccation, this can also be seen with soft tissue that has been traumatized.

PUTREFACTION

Putrefaction is the biological process which liquefies us. The agent of putrefaction is mainly the anaerobic bacteria within us. This fermentive process is fueled by the carbohydrates, proteins and fats released by autolysis. This process creates gasses (bloating), alcohols, acids and colour changes due to the decomposition of blood and bile pigment in the tissues changing colour with increased acidity.

3. **First colour change** (except browns and black during autolysis due to desiccation)
    a. **Blood** - will turn a greenish colour – bruises may turn red/brown
    b. **Tissue** – Gray – greenish/blue or yellow (colour depends on acidity or oxygen levels)


Fig. 4. Green tinge to tissue

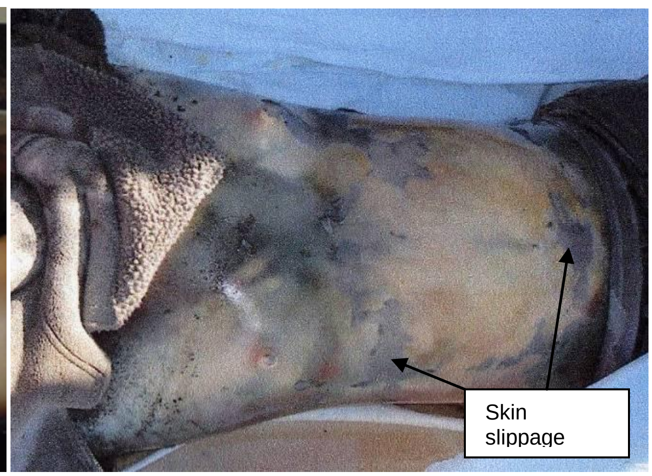


Fig. 5. Gray- green and yellow tissue

4. **Full Bloat***, in combination with*
    a. **Blood** – Generally deeper purple colour
    b. **Tissue** – Majority Red, there may be other colours present

Fig. 6. Red tissue with yellow present (majority is red)

Fig. 7. Red tissue with abdominal and face bloat

5. **Post Bloat**
    a. **Blood -** brown to black
    b. **Tissue –** Brown to black

Fig. 8. Black and brown tissue with liquefaction of internal tissues and organs

SKELETONIZATION

Skeletonization is the process by which the tissues liquefy as the result of autolysis and putrefaction to expose the bone. Tissues consumed by fire, maggots or scavenger s are considered separate from the process of tissue decomposition.

6. **First sight of bone** (less than ½ of the total bone is exposed)

These bodies will exhibit the signs of stage 5 putrefaction with liquefaction of tissue in some areas exposing bone. This is not to be confused tissue removed by scavenger or insect activity which can expose bone. Scavenger or maggot activity is often seen before post bloat putrefaction.

Tissue – Black and brown

Bone – exposed in extremities or areas of shallow tissue depth.

Fig. 9 Liquefying tissue (brown or black) with some bone exposure.

7. **More that ½ bone exposed**

This is a proportional estimate of how much tissue is present as opposed to bone exposed. If more than half the skeleton is exposed but there is still more than 5% of tissue remaining, it is estimated to be a 7.

8. **Total Skeletonization**

This is a proportional estimate of how much tissue remains on the skeleton. If there is only a very small amount of tissue left under 5%, consisting of dry tissue or tendons, it is scored as an 8.

ENVIRONMENTAL FACTORS (Alternate States of Decomposition)

Environmental factors are external influences to the normal course of baseline decomposition due to variations in temperature, humidity, acidity, fungi or bacteria. Conditions may trigger the development of one or more of these four environmentally dependant states of mummification, dry or wet moulding or adipocere development on the same cadaver. Without the appropriate environmental conditions, the cadaver will follow the normal progression of base-line decomposition without the manifestation of any of these states.

These environmental factors are all scored by the range of how much is present.

- 1 - present on any part of the body
- 2 - present on less than half the body
- 3 - more than half but less than total
- 4 - total formation on every surface of the body

<u>MUMMIFICATION</u>

Mummification happens when the moisture in the tissue is evaporated directly into the atmosphere. Mummification will happen in a dry environment, either hot or cold. Different parts of the body can mummify if exposed to the elements while others will follow the normal process of putrefaction in a dry environment if covered or protected by clothing. Mummified tissue becomes resistant to decomposition and insects due to the absence of water.

Fig. 10 Tissue mummification – note, the head became mummified before he lost his head hair due to autolysis.

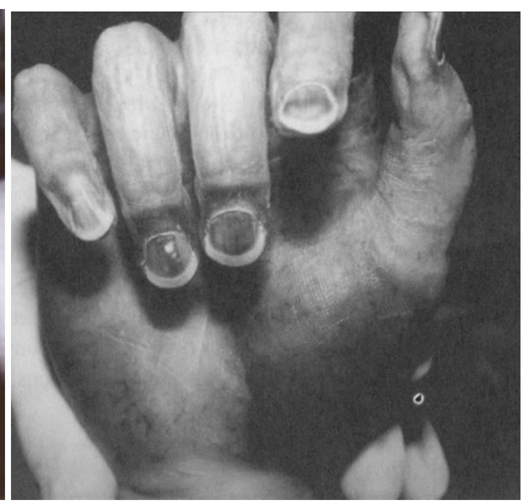


Fig. 11 The exposed hand has become mummified before autolysis separated the epidermis from the dermis

WET MOULDING

Wet moulding is the visible presence of fungi on a wet substrate. Wet moulding can occur in a moist but cool environment.

Fig. 12 Wet Moulding – Moist, cool environment

DRY MOULDING

Dry moulding is the visible presence of fungi on a desiccated substrate.

The substrate for this type of moulding is generally a dark red colour. It can occur in dry, cool environments. This type of moulding is often seen on bodies stored in coolers for a long time in the morgue.

Fig. 13 Dry Moulding – Dry cool t environment

Fig. 14 Dry Moulding (probably penicillin (*penecillium)* fungi)

ADIPOCERE FORMATION

Adipocere is a grey to white hard or soft soapy-like substance which is formed over time from the conversion of fatty tissues in the body. There are a number of conditions which must be present before adipocere will form. It will generally form in a low oxygen, acidic, wet environment within a certain temperature range (warm but not hot) with the presence of bacteria, specifically C. *perfringens*. Adipocere may take months or years to form. Adipocere tissue will not decompose. It is resistant to the further action of bacteria or fungi due to it's alkalinity. Typically you will see adipocere formation on bodies which have been underwater or have been buried in an impermeable shroud for a long period of time.

Fig. 15 Adpipocere can become hard and crumbly over time
The colour can be white or yellow.

Fig. 16 Adipocere will hold the original shape of the tissue,
including trauma wounds. This is the adipocere tissue beneath the jeans which have been removed.

Part II. Decomposition Scoring Sheet

Baseline Decomposition

Autolysis

No visible changes	0
First visible change Liver or rigor mortis	1
First tissue change Hair/skin slippage or epidermal bullae, Marbling of blood in the vein – red colour only Brown/black colour of drying tissue	2

Putrefaction

First colour change (exp. Brown or black) **Blood** – Greenish-Bruises may turn red/brown **Tissue.** Gray - Greenish/Blue or yellow Onset of abdominal swelling	3
Full Bloat - *in combination with…* **Blood** – Deep red to purple **Tissue** – Red (majority)	4
Post Bloat **Blood** – Black **Tissue**- Brown to Black	5

Skeletonization

First sign of bone (less than ½ exposed)	6
More than ½ of bone exposed	7
Total skeletonization (small fragments of tissue or tendons)	8

Alternate States

Mummification

Small portion only	1
Partial – less than ½	2
More than ½	3
Total	4

Wet Moulding

Fungal growth on wet tissues Small portion only	5
Partial - less than 1/2	6
More than 1/2	7
Total	8

Dry Moulding

Fungal growth on Dry tissue (red tissue) Small portion only	9
Partial – less than ½	10
More than ½	11
Total	12

Adipocere

Transformation of tissue into gray, or white waxy/soap - Small portion	13
Partial – less than ½	14
More than ½	15
Total	16

NOTES:

Baseline decomposition – One score 0 – 8 for each body. Chose the LATEST STAGE if in-between.

This excludes tissue consumption by maggots or scavengers.

Alternate States of decomposition

Score 0 – 16 *If applicable* – largest presence of an environmental variable (primary)

There may be two kinds of environmental variables present score

Score 0-16 if there is a second stage present (secondary).

Part III. The Observer Error Answer Sheet

Inter observer Study

Name: _____________ Date: _________Years of Police Service: ________Group: _______________

Please circle one baseline classification from 0 to 8 for each case (photograph). The numbers on the photographs correspond to the answer numbers. Score the presence of any environmental factors visible on the photographs. Please select N/A (not applicable) if no environmental factors are visible.

1. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
2. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
3. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
4. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
5. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
6. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
7. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16
8. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
		Dry Moulding:	N/A 5 6 7 8
		Wet Moulding:	N/A 9 10 11 12
		Adipocere:	N/A 13 14 15 16

9.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
10.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
11.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
12.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
13.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
14.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
15.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
16.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
17.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
18.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16

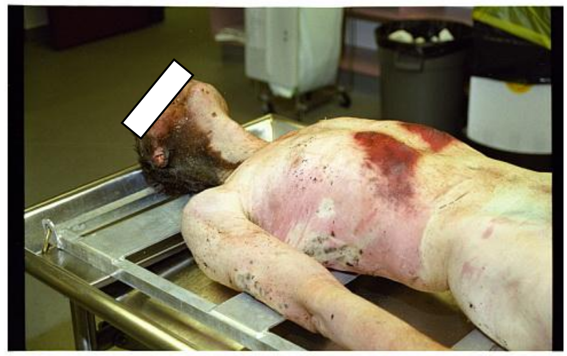
19.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
20.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
21.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
22.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
23.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
24.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
25.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
26.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
27.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16
28.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A	1	2	3	4
			Dry Moulding:	N/A	5	6	7	8
			Wet Moulding:	N/A	9	10	11	12
			Adipocere:	N/A	13	14	15	16

29.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
30.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
31.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
32.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
33.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
34.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
35.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
36.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
37.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16
38.	Baseline: 0 1 2 3 4 5 6 7 8	Alternate states:	Mummification:	N/A 1 2 3 4
			Dry Moulding:	N/A 5 6 7 8
			Wet Moulding:	N/A 9 10 11 12
			Adipocere:	N/A 13 14 15 16

39. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states: Mummification:	N/A	1	2	3	4
	Dry Moulding:	N/A	5	6	7	8
	Wet Moulding:	N/A	9	10	11	12
	Adipocere:	N/A	13	14	15	16
40. Baseline: 0 1 2 3 4 5 6 7 8	Alternate states: Mummification:	N/A	1	2	3	4
	Dry Moulding:	N/A	5	6	7	8
	Wet Moulding:	N/A	9	10	11	12
	Adipocere:	N/A	13	14	15	16

Part IV Observer error study Photo-booklet

001



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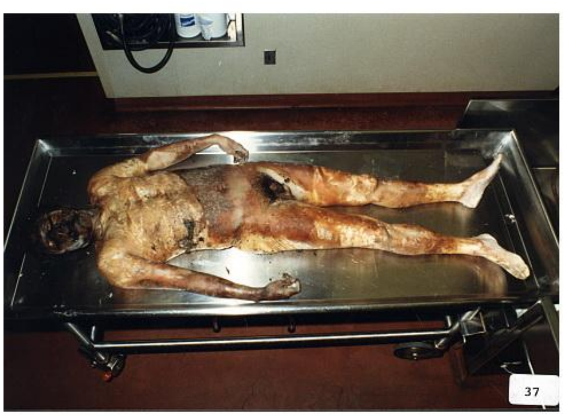

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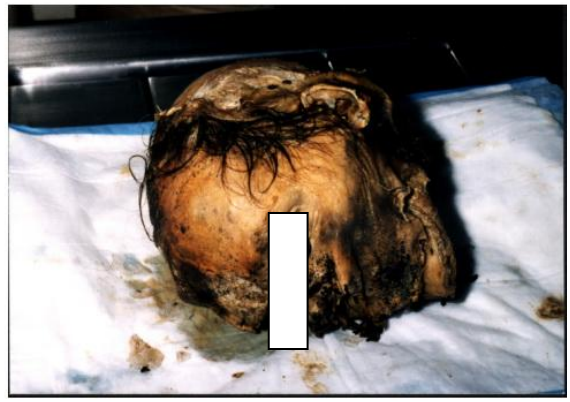

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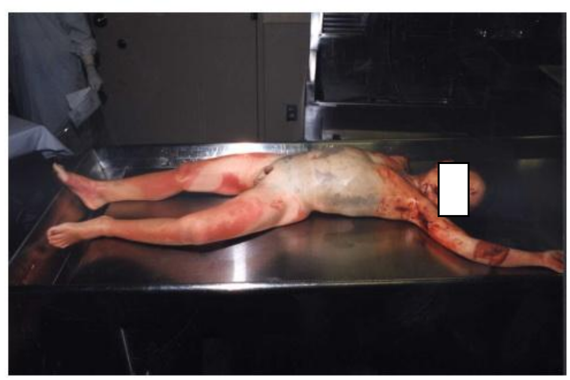

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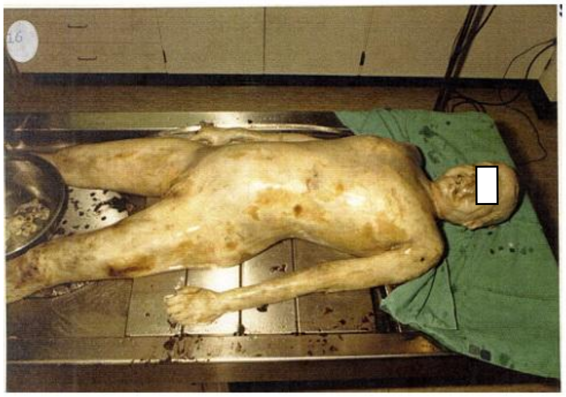

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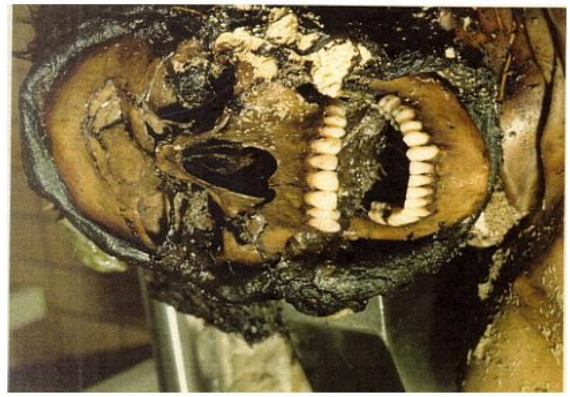

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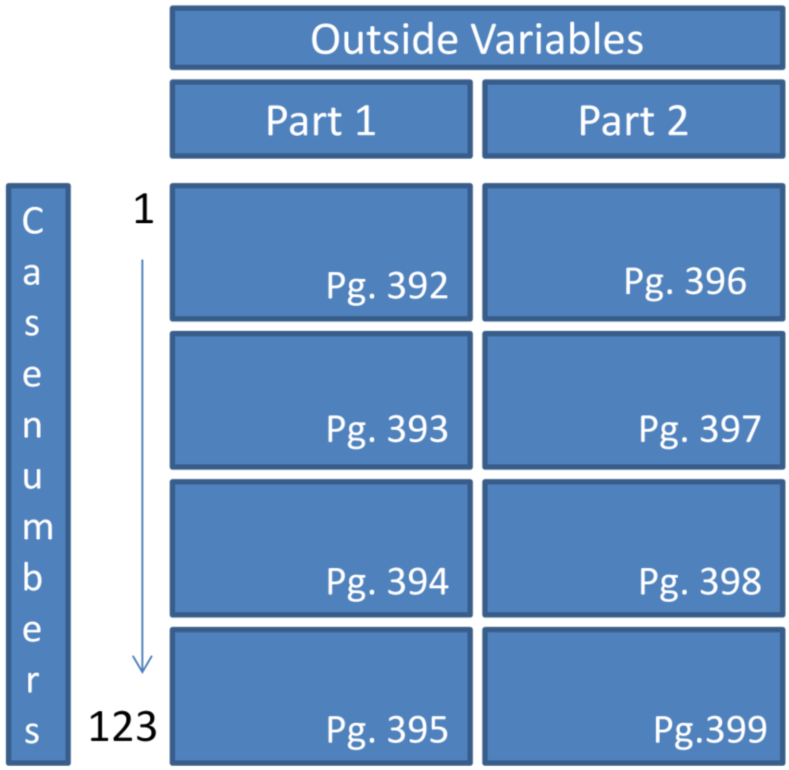
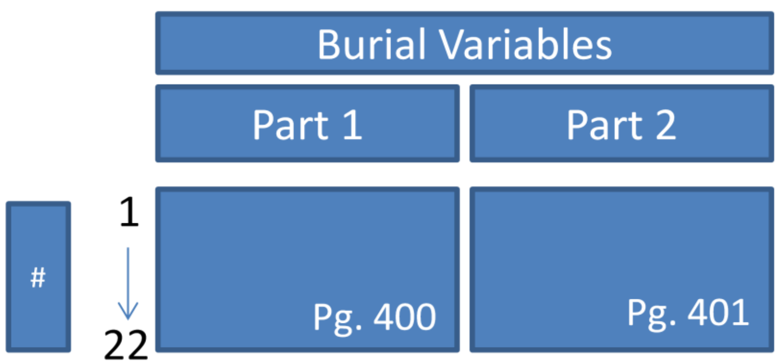
NB: For the original test booklet, each photograph was 4 to a page and 4 ½ x 3 ½ inches in size. There were no shapes on the original photographs to conceal identity.

Appendix B. Project Dataset

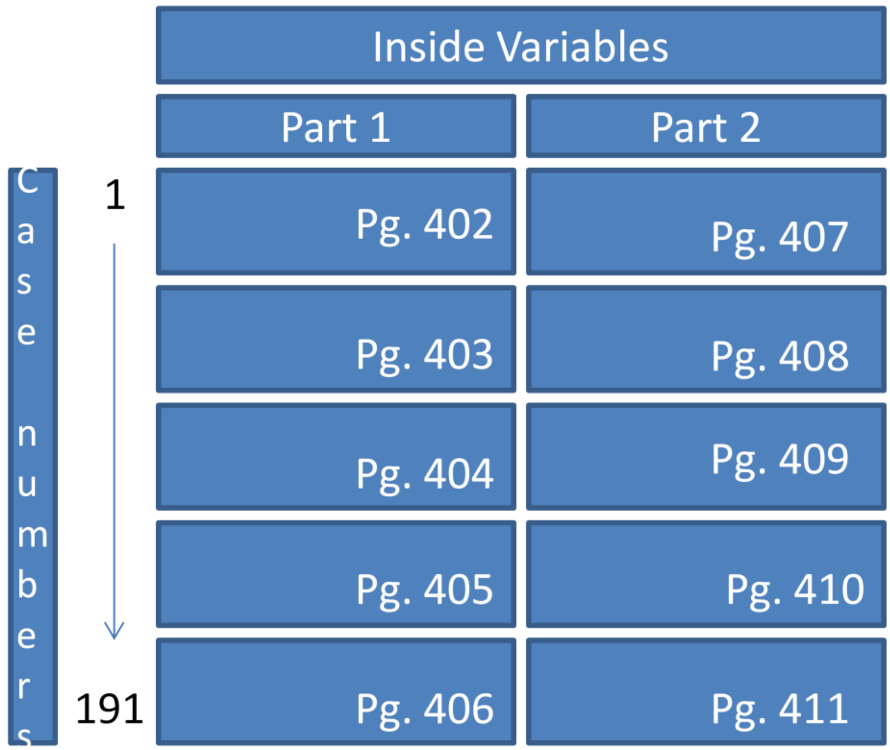
Outdoors on the Surface Cases: Reference system for dataset



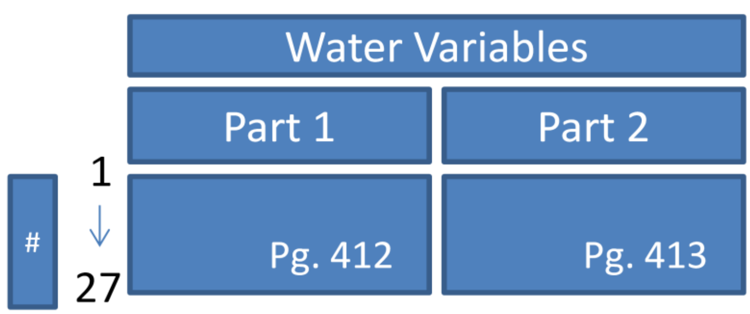
Burial Cases: Reference system for dataset



Inside Cases: Reference system for dataset



Water Cases: Reference system for dataset



Outdoor Surface Part 1

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Total Precip	ADD Score	RLDV	Sex	Age	pop	Body size	Illness/Disease	Drugs	Alcohol	structure	urban/rural	surface/buried	Land 2
1	12	4	5	13	0.2	127.8	5	1	16	1	1	3	1	1	2	2	1	6
2	6	12	1	13	66.2	35.6	1	1	29	1	2	1	3	2	1	1	1	7
3	23	12	1	10	2.7	0	-1	2	21	3	1	1	0	2	2	2	1	4
4	1	10	10	10	0	0	-1	2	14	1	1	1	1	1	2	1	1	7
5	7	4	4	12	1.8	15	-1	2	25	1	1	1	1	2	1	2	1	1
6	3	2	2	13	14.2	16.2	-1	2	53	1	2	1	1	1	2	2	1	1
7	3	8	8	13	0	32.8	1	2	21	3	2	1	3	2	2	2	1	1
8	9	11	11	13	65	72	3	1	20	8	2	3	0	2	2	2	1	1
9	5	11	11	13	61	33	1	2	25	1	1	3	3	2	2	1	2	2
10	2	8	8	13	0	42	1	1	51	1	2	1	0	2	2	2	1	1
11	2	11	11	7	5.6	3.5	-1	1	31	1	2	3	0	1	2	2	1	1
12	1	4	4	10	0	0	-1	1	56	1	2	3	0	2	1	1	1	7
13	1	7	7	13	0	17	-1	1	0.1	3	1	1	1	1	2	1	1	7
14	2	9	9	14	0	35	1	1	33	1	2	3	3	2	2	1	1	2
15	1	3	3	12	0	0	-1	1	28	3	3	3	0	2	2	2	1	1
16	1	3	3	12	0	0	-1	1	34	1	2	3	0	1	2	2	1	1
17	2	4	4	13	0	12.9	-1	2	16	1	1	3	0	1	2	1	1	2
18	2	10	10	9	0	19.3	-1	1	43	1	2	3	0	2	2	1	1	2
19	1	6	6	14	0	17	-1	1	31	1	3	3	0	2	2	1	1	7
20	1	1	1	8	3.6	0	-1	1	46	1	2	2	2	2	2	1	1	7
21	1	5	5	8	4.5	14.6	-1	1	66	1	2	3	0	2	2	2	1	1
22	1	5	5	8	0	8.4	-1	1	55	1	2	3	0	1	2	1	1	6
23	2	1	1	8	0	0	-1	1	30	1	2	2	2	1	2	1	1	8
24	1	2	2	8	0.2	0	-1	2	25	4	1	2	2	2	2	1	1	8
25	2	6	6	8	7.6	21.1	1	1	25	2	2	1	1	1	2	1	3	7
26	2	7	7	8	0	38.9	1	2	55	1	2	1	1	1	1	1	1	7
27	1	7	7	8	47.8	18.5	-1	2	29	1	2	1	3	1	2	2	1	7
28	1	8	8	8	0	16.2	-1	1	25	1	2	1	1	2	2	1	1	7
29	1	9	9	8	0	17.3	-1	2	46	1	2	1	1	1	2	1	1	2
30	1	9	9	8	0	17	-1	1	19	1	2	1	2	2	2	1	1	7
31	2	4	4	8	0	14.9	-1	1	27	1	1	1	3	1	2	2	1	2
32	1	9	9	8	0	12.4	-1	2	34	1	3	1	1	1	2	1	1	7
33	1	7	7	8	0	24.1	1	1	60	1	2	1	1	1	2	1	1	7
34	1	6	6	8	1.4	15.8	-1	1	26	1	2	2	1	1	1	1	1	7

Outdoor Surface Part 1

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Total Precip	ADD Score	RLDV	Sex	Age	pop	Body size	Illness/Disease	Drugs	Alcohol	structure	urban/rural	surface/buried	Land 2
35	1	3	3	8	0	3.2	-1	1	26	1	2	1	1	1	1	2	2	7
36	2	11	11	8	0	9.2	-1	2	45	1	2	1	1	2	2	2	1	7
37	2	8	8	12	0	34.6	-1	2	0	3	1	1	1	1	2	1	1	7
38	2	10	10	13	1.6	13.2	-1	1	41	1	2	1	3	2	2	1	1	2
39	2	12	12	13	0	0	-1	1	40	1	3	1	3	2	2	1	1	7
40	3	10	10	13	26	38.1	-1	1	20	4	1	1	0	1	2	2	2	2
41	2	7	8	13	0	17.2	-1	2	11	1	1	1	0	1	2	2	2	1
42	42	5	6	14	16	862	7	2	21	1	1	1	3	2	2	1	1	1
43	3	6	6	14	16	43	-1	1	54	1	2	1	0	2	2	2	1	2
44	3	6	6	14	16	43	-1	2	54	1	2	1	0	1	2	2	1	2
45	22	1	1	13	64	87	1	2	23	1	1	1	0	1	2	2	1	3
46	2	8	8	14	0	45	-1	1	24	1	2	3	0	1	2	2	1	1
47	2	8	8	14	0	45	-1	1	56	1	2	3	0	1	2	2	1	1
48	2	8	8	14	0	45	-1	2	56	1	1	3	0	1	2	2	1	1
49	3	8	8	14	0	67	1	1	16	1	2	3	0	1	2	2	1	3
50	3	8	8	14	0	67	1	1	70	1	3	3	0	1	1	2	1	3
51	3	6	6	14	5	52	-1	1	38	1	2	3	0	1	2	1	1	7
52	20	1	1	13	71.3	206	2	1	27	1	2	1	3	2	1	2	1	2
53	5	2	2	14	7	20	-1	1	32	1	2	1	3	2	1	1	1	7
54	3	10	10	10	0	25	-1	2	13	1	1	3	0	1	1	1	1	7
55	3	10	10	10	0	25	-1	1	42	1	2	3	0	1	1	1	1	7
56	3	11	11	7	1.8	32.7	-1	1	43	1	2	3	0	2	2	1	1	2
57	2	1	1	7	15.2	3.3	-1	1	66	1	3	3	0	1	2	2	1	8
58	2	9	9	7	2.8	28	-1	2	19	1	1	3	0	2	2	2	1	9
59	1	10	10	10	0	0	-1	1	54	1	3	3	0	1	2	1	1	2
60	2	8	8	7	0	44.1	-1	2	13	1	1	3	0	1	2	2	1	2
61	1	2	2	13	4.4	0	-1	2	31	3	2	1	0	1	2	1	1	2
62	1	11	11	13	19.4	8.9	-1	1	28	3	3	1	0	2	1	1	1	9
63	1	7	7	13	8.5	11.2	-1	1	47	3	2	3	0	2	1	1	1	9
64	1	4	4	13	0	12.9	-1	1	18	1	2	3	0	1	2	1	1	2
65	1	6	6	13	0	18.8	-1	1	28	1	2	3	0	1	2	1	1	9
66	3	6	6	8	1.9	62.1	1	1	33	1	2	1	0	1	2	2	1	1
67	3	5	5	8	1.9	34.2	-1	1	60	1	2	2	2	1	1	1	1	6
68	1	3	3	8	0	0.5	-1	1	49	1	3	1	1	1	1	1	3	9
69	1	4	4	8	0	7.8	-1	2	25	1	1	1	1	1	2	1	1	7

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Total Precip	ADD Score	RLDV	Sex	Age	pop	Body size	Illness/Disease	Drugs	Alcohol	structure	urban/rural	surface/buried	Land 2
						Outdoor Surface Part 1												
70	1	8	8	8	0	20	-1	2	72	1	4	1	1	1	1	1	1	9
71	2	6	6	8	7.8	36	-1	1	25	1	2	1	1	1	2	2	1	1
72	1	7	7	8	0	13	-1	1	49	1	2	1	3	2	2	2	1	7
73	2	8	8	8	20.8	40.6	-1	1	23	1	1	1	3	1	2	2	3	1
74	1	9	9	8	5.6	10.8	-1	1	53	1	3	1	1	1	2	1	1	7
75	1	10	10	8	0	4.2	-1	1	59	1	3	1	1	1	2	1	1	7
76	1	3	3	8	0	5.8	-1	1	60	1	2	2	2	2	2	1	1	1
77	2	6	6	8	0	44	-1	1	61	1	3	2	2	1	1	2	1	9
78	1	7	7	8	0	20	-1	1	77	1	3	2	1	1	2	1	1	7
79	37	11	12	13	307	189.8	2	2	12	1	1	3	1	1	2	2	1	1
80	5	7	7	13	0	89.6	1	1	43	1	1	1	2	1	2	2	1	1
81	4	6	7	13	4	63	-1	2	44	1	2	2	2	2	2	2	1	2
82	3	7	7	9	14.6	43.8	-1	2	12	3	1	3	0	2	2	2	1	1
83	2	10	10	8	7.6	26	-1	1	51	3	2	1	1	1	2	1	1	7
84	4	7	8	8	1.7	71.7	-1	2	45	1	1	1	3	1	1	1	3	7
85	11	7	8	9	12.2	185.4	2	1	37	1	2	1	1	1	2	2	3	1
86	2	6	6	10	0	40.5	-1	1	32	1	3	3	0	1	2	2	1	4
87	16	2	3	7	85	0	-1	1	73	1	3	3	0	1	1	2	1	7
88	17	7	7	13	23.3	232.8	1	1	26	1	2	1	1	1	1	1	1	7
90	17	7	7	13	16	289.3	-1	2	14	1	1	3	1	1	2	2	2	1
91	31	7	8	13	73.4	590.8	-1	2	15	1	2	3	1	1	2	2	2	6
92	14	7	8	13	23	255.5	-1	1	15	1	1	3	1	1	2	2	1	1
93	340	2	1	13	1051	3311	2	2	35	1	3	1	0	2	2	1	2	1
94	37	2	4	13	128	238.2	-1	1	29	3	2	1	1	2	2	2	1	1
95	223	7	4	13	279	1034	1	1	40	1	3	3	3	2	2	2	2	1
96	9	8	9	13	2	149	-1	2	17	1	3	3	0	2	1	1	1	1
97	154	5	10	8	410	2768	2	2	80	1	1	3	0	1	2	1	3	2
98	6	8	8	8	44.7	138.9	-1	2	28	1	2	1	1	1	2	2	1	1
99	13	7	8	8	106	289	-1	1	38	5	2	1	2	1	2	1	1	2
100	120	5	9	12	158	1349	1	1	69	1	1	1	1	1	2	2	3	2
101	173	6	12	9	383	1361	1	1	41	1	3	1	3	1	2	2	1	1
102	31	8	9	13	27	528.4	-1	1	26	1	3	1	3	1	2	2	1	2
103	229	9	4	14	404	620.6	-1	2	22	3	2	3	0	1	2	2	2	2
105	263	12	9	13	782	3039	2	1	32	1	3	3	1	1	2	1	3	2
106	180	10	4	13	1149	1106	-1	2	14	1	1	1	1	1	2	2	2	1

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Total Precip	Outdoor Surface Part 1 ADD Score	RLDV	Sex	Age	pop	Body size	Illness/Disease	Drugs	Alcohol	structure	urban/rural	surface/buried	Land 2
107	203	11	5	12	142	348.5	-1	1	55	1	2	3	0	1	2	1	1	9
108	32	6	7	8	151	646.3	-1	1	50	1	2	2	3	1	2	2	1	1
109	9	6	6	8	34.5	202.1	-2	1	0.5	1	1	1	1	1	2	1	2	2
110	68	6	8	13	84	1165	-1	2	13	1	1	3	1	1	2	2	2	1
111	28	7	8	13	0	522.2	-1	2	17	1	2	3	1	1	2	2	2	9
112	67	7	8	13	34	625	-1	2	36	1	1	2	3	1	2	1	1	1
113	96	5	8	13	43	1574	-1	1	25	1	2	1	1	1	2	2	1	1
114	336	3	2	13	1389	3388	2	1	22	1	2	1	0	1	2	2	1	1
115	336	3	2	13	1389	3388	2	1	25	1	2	1	0	1	2	2	1	1
116	260	7	4	13	1137	2383	1	1	12	1	1	1	0	1	2	2	2	1
117	247	5	4	14	393	1915	1	2	31	3	2	1	0	2	2	2	2	1
118	32	6	6	10	74.9	485.7	-1	1	26	3	2	3	0	2	2	2	1	1
119	32	6	7	10	74.9	485.7	-1	2	20	3	2	3	0	2	2	2	1	1
120	175	9	3	10	104	264.7	-1	2	26	3	2	3	0	2	2	2	1	1
121	11	9	9	8	39.1	228	-1	2	18	1	1	1	1	1	2	2	2	1
122	25	9	10	14	16.9	306.6	-1	2	12	1	1	1	1	1	2	2	1	1
123	217	7	2	14	109	2075	1	2	40	1	2	3	0	1	2	2	2	1

Outdoor Surface Part 2																
Case 2	Terrain	Surface	Shaded	MOD	Trauma	# of Blows	blood loss	body disposal	Clothing	Shroud	objects on body	Scavenging	Insects	Decomp Score	Primary	Secondary
1	1	3	1	1	3	6	1	1	4	1	0	0	0	0	0	0
2	1	1	3	4	7	0	0	0	1	2	0	0	0	0	0	0
3	1	1	1	1	7	0	0	2	4	1	0	1	0	0	8	0
4	3	3	3	1	4	0	1	1	4	2	0	0	0	0	0	0
5	1	3	3	1	3	7	1	2	2	4	2	0	0	0	0	0
6	3	3	3	1	3	6	0	2	4	2	0	0	0	0	0	0
7	1	3	3	1	2	7	2	1	2	1	0	0	1	0	0	0
8	2	3	3	1	1	1	1	1	1	1	0	0	0	0	0	0
9	1	3	1	1	6	0	0	2	4	2	0	0	0	0	0	0
10	2	3	2	1	1	1	3	1	1	1	0	0	0	0	0	0
11	1	3	2	1	1	10	2	1	1	1	0	0	0	0	0	0
12	1	2	3	1	3	10	1	1	2	1	0	0	0	0	0	0
13	1	2	1	1	5	0	0	1	4	1	0	0	0	0	0	0
14	1	3	2	1	2	1	1	1	1	1	0	0	0	0	0	0
15	3	1	2	1	1	1	1	1	1	1	0	0	0	0	0	0
16	1	1	2	1	1	1	1	1	1	1	0	0	0	0	0	0
17	2	2	1	1	1	1	1	1	4	1	0	0	0	0	0	0
18	2	3	2	1	1	1	1	1	1	1	0	0	0	0	0	0
19	1	2	2	1	2	1	2	1	1	1	0	0	0	0	0	0
20	1	1	1	3	3	1	1	1	1	1	0	0	0	0	0	0
21	1	3	2	3	1	1	3	1	1	1	0	0	0	0	0	0
22	1	3	1	3	2	2	3	1	3	1	0	0	0	0	0	0
23	1	3	3	3	3	1	2	1	4	1	0	0	0	0	0	0
24	1	3	3	3	3	1	1	1	4	1	0	0	0	0	0	0
25	1	3	1	3	4	0	0	1	4	1	0	0	0	0	0	0
26	1	4	3	2	7	0	0	1	4	1	0	0	0	0	0	0
27	1	2	1	3	3	1	2	1	4	1	0	0	0	0	0	0
28	1	4	1	3	3	1	0	1	4	1	0	0	0	0	0	0
29	1	3	2	2	7	0	0	1	4	1	0	0	0	0	0	0
30	1	4	1	3	3	1	1	1	3	1	0	0	0	0	0	0
31	1	3	2	4	7	0	0	1	4	1	0	0	0	0	0	0
32	1	4	3	4	3	1	2	1	4	1	0	0	0	0	0	0
33	1	4	2	3	2	10	4	1	4	1	0	0	0	0	0	0
34	2	4	1	4	3	0	1	1	4	1	0	0	0	0	0	0

Outdoor Surface Part 2

Case 2	Terrain	Surface type	Shaded	MOD	Trauma	# of Blows	blood loss	body disposal	Clothing	Shroud	objects on body	Scavenging	Insects	Decomp Score	Primary	Secondary
35	1	2	1	4	3	1	1	1	4	1	4	0	0	0	0	0
36	1	1	1	3	7	0	0	1	4	1	0	0	0	0	0	0
37	1	1	1	1	3	0	0	2	4	4	0	0	0	1	1	0
38	1	3	1	1	4	0	1	1	2	1	0	0	0	1	0	0
39	1	2	1	1	4	0	0	1	4	1	0	0	0	1	0	0
40	1	2	1	1	3	10	1	2	4	3	2	0	0	1	1	0
41	1	3	2	1	2	1	1	2	3	1	1	0	0	1	0	0
42	2	3	3	1	3	2	1	2	2	1	1	0	3	1	1	0
43	1	3	1	3	1	1	2	1	4	1	0	0	0	1	0	0
44	1	3	1	1	1	2	2	1	4	1	0	0	0	1	0	0
45	2	2	2	1	2	0	2	1	3	2	0	2	0	1	1	0
46	1	3	1	1	1	2	0	1	4	1	0	0	0	1	0	0
47	1	3	2	1	1	1	0	1	4	1	0	0	0	1	0	0
48	1	3	1	1	1	1	0	1	4	1	0	0	0	1	0	0
49	1	3	1	1	1	0	0	1	4	1	0	0	0	1	0	0
50	1	3	1	1	1	0	0	1	4	1	0	0	0	1	0	0
51	1	2	1	1	1	1	2	1	4	1	0	0	0	1	0	0
52	2	3	1	1	1	2	2	2	1	3	0	0	0	1	0	0
53	1	1	3	1	2	6	3	2	3	1	0	0	0	1	0	0
54	1	1	3	1	5	0	0	1	4	1	0	0	0	1	0	0
55	1	1	3	3	5	0	0	1	4	1	0	0	0	1	0	0
56	1	2	1	1	2	3	1	1	4	1	0	0	0	1	0	0
57	1	2	1	1	2	1	2	1	2	1	0	0	0	1	0	0
58	2	2	1	1	3	3	1	1	3	1	0	0	0	1	0	0
59	2	2	1	1	1	1	1	1	4	1	0	0	0	1	0	0
60	1	3	2	1	2	7	1	1	1	1	0	0	0	1	0	0
61	1	1	1	1	3	8	2	1	3	1	0	0	0	1	0	0
62	2	1	3	3	1	1	2	1	4	1	0	0	0	1	0	0
63	1	3	3	1	3	10	3	1	4	1	0	0	0	1	0	0
64	2	2	1	1	1	2	4	1	4	1	0	0	0	1	0	0
65	3	3	1	1	3	10	1	1	4	1	0	0	0	1	0	0
66	1	3	2	3	4	0	0	1	4	1	0	0	1	1	0	0
67	2	1	2	3	2	4	4	1	3	1	0	0	0	1	0	0
68	2	1	3	3	4	0	0	1	4	1	0	0	0	1	0	0
69	1	1	2	3	3	1	2	1	4	1	0	0	0	1	0	0

Outdoor Surface Part 2

Case 2	Terrain	Surface type	Shaded	MOD	Trauma	# of Blows	blood loss	body disposal	Clothing	Shroud	objects on body	Scavenging	Insects	Decomp Score	Primary	Secondary
70	3	1	2	4	3	1	0	1	4	1	0	0	0	1	0	0
71	1	3	2	3	4	0	0	1	4	1	0	0	0	1	0	0
72	1	1	2	3	3	1	1	1	3	1	0	0	0	1	0	0
73	3	3	2	3	4	0	0	1	4	1	0	0	0	1	0	0
74	1	1	3	3	3	1	2	1	4	1	0	0	0	1	0	0
75	1	1	2	4	3	1	0	1	4	1	0	0	0	1	0	0
76	2	3	3	3	3	1	1	1	4	1	0	0	0	1	0	0
77	3	1	1	3	5	0	0	1	4	1	0	0	0	1	0	0
78	1	1	1	3	1	1	2	1	4	1	0	0	0	1	0	0
79	1	3	3	1	2	10	3	1	1	1	0	0	0	2	8	0
80	1	3	3	1	3	0	1	2	4	1	1	1	2	2	0	0
81	2	3	3	1	4	0	1	2	2	1	3	1	0	2	0	0
82	1	2	3	1	3	3	1	2	1	1	3	0	1	2	0	0
83	1	1	1	4	7	0	0	1	4	1	0	0	0	2	0	0
84	1	1	3	4	7	0	0	1	4	1	0	0	1	2	0	0
85	1	3	3	1	3	2	1	2	4	4	0	0	0	3	0	0
86	2	2	1	1	1	3	2	1	4	1	0	0	1	3	0	0
87	1	1	3	1	1	4	2	1	4	1	0	0	0	3	1	0
88	2	1	2	1	5	0	0	2	4	1	0	0	0	4	1	0
90	1	3	2	1	2	10	3	2	1	1	0	1	1	5	0	0
91	1	3	2	1	3	10	1	2	1	1	0	0	0	5	6	14
92	1	3	3	1	3	8	1	2	1	1	0	1	2	5	0	0
93	3	3	3	1	2	10	3	2	1	2	2	2	0	5	0	0
94	1	3	2	1	2	5	1	1	2	1	0	1	0	5	2	0
95	2	3	3	1	1	3	1	2	4	2	0	1	0	5	2	0
96	2	3	2	1	3	1	0	1	3	1	0	0	3	5	0	0
97	1	3	2	2	7	0	0	2	1	2	0	0	0	5	1	1
98	1	3	3	1	4	0	0	2	1	1	3	0	4	5	0	0
99	2	3	1	3	7	0	0	1	4	3	0	0	4	5	1	0
100	1	3	2	1	3	0	0	2	4	3	0	0	0	6	0	0
101	1	3	3	1	1	1	1	2	4	1	0	2	0	6	3	1
102	1	3	3	1	3	1	0	2	4	1	0	2	0	6	2	1
103	1	3	1	1	3	10	0	2	4	1	0	0	0	6	0	0
105	1	3	1	1	4	0	1	2	4	1	0	0	0	6	0	0

Outdoor Surface Part 2

Case 2	Terrain	Surface type	Shaded	MOD	Trauma	# of Blows	blood loss	body disposal	Clothing	Shroud	objects on body	Scavenging	Insects	Decomp Score	Primary	Secondary
106	1	3	3	1	3	1	1	2	1	1	0	0	0	6	0	0
107	2	2	1	1	2	6	2	1	4	1	0	0	3	6	0	0
108	1	3	2	3	2	2	4	1	4	1	0	1	3	6	0	0
109	1	3	3	2	7	0	0	2	1	2	0	0	0	6	0	0
110	2	3	3	1	3	7	1	2	1	1	1	0	0	7	0	0
111	3	2	1	1	3	10	1	2	1	1	4	2	0	7	2	0
112	1	3	2	4	7	0	0	1	4	1	0	0	4	7	3	0
113	1	3	2	3	7	0	0	1	4	1	0	3	0	7	2	0
114	2	3	3	1	3	0	1	1	4	1	0	0	0	7	0	0
115	1	3	3	1	3	3	1	1	4	1	0	0	0	7	0	0
116	1	3	3	1	3	2	0	2	4	1	0	0	0	7	0	0
117	1	3	3	1	3	4	1	2	4	1	0	0	3	7	2	0
118	2	3	3	1	2	5	2	1	4	1	3	2	4	7	3	0
119	2	3	2	1	2	3	2	1	4	1	0	3	3	7	2	9
120	1	3	2	1	2	6	1	1	4	1	0	3	0	7	0	0
121	1	3	3	1	4	0	0	2	1	1	0	0	4	7	0	0
122	1	3	3	1	4	0	0	2	2	2	0	0	4	7	0	0
123	1	3	1	1	2	1	0	2	4	1	0	2	0	8	0	0

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Total Precip	Burial Part 1 ADD score	RLDV	Sex	Age	pop	Body size	Illness/Disease	Alcohol	Drugs
1	5	11	11	13	61	33	1	2	25	1	1	3	2	3
2	1	3	3	8	0	3.2	-1	1	26	1	2	1	1	1
3	3	10	10	13	26	38.1	-1	1	20	4	1	1	1	0
4	2	7	8	13	0	17.2	-1	2	11	1	1	1	1	0
5	2	8	8	8	20.8	40.6	-1	1	23	1	1	1	1	3
6	11	7	8	9	12.2	185.4	2	1	37	1	2	1	1	1
7	17	7	7	13	16	289.3	-1	2	14	1	1	3	1	1
8	31	7	8	13	73.4	590.8	-1	2	15	1	2	3	1	1
9	340	2	1	13	1051	3310.5	2	2	35	1	3	1	2	0
10	223	7	4	13	279	1034	1	1	40	1	3	3	2	3
11	154	5	10	8	410	2767.6	2	2	80	1	1	3	1	0
12	120	5	9	12	158	1348.8	1	1	69	1	1	1	1	1
13	229	9	4	14	404	620.6	-1	2	22	3	2	3	1	0
14	263	12	9	13	782.2	3039.1	2	1	32	1	3	3	1	1
15	180	10	4	13	1149	1106.4	-1	2	14	1	1	1	1	1
16	9	6	6	8	34.5	202.1	-2	1	0.5	1	1	1	1	1
17	68	6	8	13	84	1164.9	-1	2	13	1	1	3	1	1
18	28	7	8	13	0	522.2	-1	2	17	1	2	3	1	1
19	260	7	4	13	1137	2383	1	1	12	1	1	1	1	0
20	247	5	4	14	392.9	1915.3	1	2	31	3	2	1	2	0
21	11	9	9	8	39.1	228	-1	2	18	1	1	1	1	1
22	217	7	2	14	109	2074.5	1	2	40	1	2	3	1	0

Burial Part 2

Case 2	Terrain	Shaded	MOD	Trauma	# of Blows	blood loss	body disposal	Clothing	Shroud	objects on body	Scavenging	Insects	Decomp Score	Primary	Secondary
1	1	1	1	6	0	0	2	4	2	0	0	0	0	0	0
2	1	1	4	3	1	1	1	4	1	4	0	0	0	0	0
3	1	1	1	3	10	1	2	4	3	2	0	0	1	1	0
4	1	2	1	2	1	1	2	3	1	1	0	0	1	0	0
5	3	2	3	4	0	0	1	4	1	0	0	0	1	0	0
6	1	3	1	3	2	1	2	4	4	0	0	0	3	0	0
7	1	2	1	2	10	3	2	1	1	0	1	1	5	0	0
8	1	2	1	3	10	1	2	1	1	0	0	0	5	6	14
9	3	3	1	2	10	3	2	1	2	2	2	0	5	0	0
10	2	3	1	1	3	1	2	4	2	0	1	0	5	2	0
11	1	2	2	7	0	0	2	1	2	0	0	0	5	1	1
12	1	2	1	3	0	0	2	4	3	0	0	0	6	0	0
13	1	1	1	3	10	0	2	4	1	0	0	0	6	0	0
14	1	1	1	4	0	1	2	4	1	0	0	0	6	0	0
15	1	3	1	3	1	1	2	1	1	0	0	0	6	0	0
16	1	3	2	7	0	0	2	1	2	0	0	0	6	0	0
17	2	3	1	3	7	1	2	1	1	1	0	0	7	0	0
18	3	1	1	3	10	1	2	1	1	4	2	0	7	2	0
19	1	3	1	3	2	0	2	4	1	0	0	0	8	0	0
20	1	3	1	3	4	1	2	4	1	0	0	3	7	2	0
21	1	3	1	4	0	0	2	1	1	0	0	4	7	0	0
22	1	1	1	2	1	0	2	4	1	0	2	0	8	0	0

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Inside Part 1			RLDV	Aver Temp	Sex	Age	Pop Group
					Max Temp	Min Temp	ADD Score					
1	2	2	3	13	20	20	20	-1	20	2	29	1
2	2	1	1	13	20	20	20	-1	20	2	81	1
3	3	4	4	13	20	20	40	1	20	1	71	1
4	3	4	4	13	20	20	40	1	20	1	32	1
5	22	1	1	10	20	20	440	-2	-16	1	38	1
6	6	11	11	14	20	20	100	4	20	1	63	1
7	2	3	3	13	20	20	20	-1	20	2	4	1
8	3	11	11	7	20	20	60	2	20	1	64	1
9	2	10	10	7	20	20	40	1	20	2	58	1
10	2	10	10	7	20	20	40	1	20	1	65	1
11	1	11	11	7	20	20	20	-1	20	2	54	1
12	1	11	11	7	20	20	20	-1	20	1	61	1
13	2	11	11	10	20	20	40	1	20	1	49	3
14	1	9	9	9	20	20	20	-1	20	2	32	3
15	1	3	3	6	20	20	20	-1	20	1	26	3
16	2	6	6	9	20	20	40	1	20	2	26	3
17	2	5	5	7	20	20	40	1	20	1	39	1
18	2	2	2	7	20	20	40	1	20	1	66	1
19	2	5	5	7	20	20	40	1	20	2	75	1
20	5	5	5	10	20	20	100	4	20	2	31	1
21	3	8	8	7	20	20	60	2	20	1	15	1
22	2	6	6	7	20	20	40	1	20	1	62	1
23	4	11	11	7	20	20	80	3	20	2	78	1
24	1	2	2	13	20	20	20	-1	20	2	80	1
25	1	2	2	13	20	20	20	-1	20	1	80	1
26	1	12	12	13	20	20	20	-1	20	1	30	1
27	1	10	10	13	20	20	20	-1	20	2	23	1
28	1	8	8	14	20	20	20	-1	20	2	20	1
29	1	6	6	14	20	20	20	-1	20	1	28	3
30	1	6	6	9	20	20	20	-1	20	1	86	3
31	1	10	10	13	20	20	20	-1	20	1	68	3
32	4	10	10	9	20	20	80	3	20	2	29	1
33	1	10	10	14	20	20	20	-2	7.1	1	45	1
34	1	12	12	13	20	20	20	-1	20	2	80	1
35	2	10	10	8	20	20	40	1	20	2	72	1

						Inside Part 1						
Case 1	**PMI DAYS**	**Month Missing**	**Month Located**	**Ecozone**	**Max Temp**	**Min Temp**	**ADD Score**	**RLDV**	**Aver Temp**	**Sex**	**Age**	**Pop Group**
36	1	10	10	8	20	20	20	-1	20	1	47	1
37	1	2	2	8	20	20	20	-1	20	1	32	5
38	1	3	3	8	20	20	20	-2	3.3	2	62	1
39	1	2	2	8	20	20	20	-1	20	1	45	1
40	1	4	4	8	20	20	20	-1	20	1	31	1
41	1	4	4	8	20	20	20	-1	20	1	60	1
42	1	4	4	8	25	25	25	-1	25	2	32	1
43	1	8	8	8	20	20	20	-1	20	1	48	7
44	2	5	5	8	20	20	40	1	20	1	51	1
45	3	7	7	8	20	20	60	2	20	1	50	1
46	1	5	5	8	20	20	20	-1	20	1	41	1
47	1	5	5	8	20	20	20	-1	20	2	60	1
48	2	10	10	8	20	20	40	1	20	1	88	1
49	1	8	8	8	20	20	20	-1	20	1	69	1
50	2	7	7	8	20	20	40	1	20	1	56	1
51	1	6	6	8	20	20	20	-1	20	1	53	1
52	1	4	4	8	20	20	20	-1	20	1	47	1
53	2	1	1	14	20	20	40	1	20	2	72	1
54	1	3	3	8	20	20	20	-1	20	2	25	2
55	4	12	12	13	20	20	80	1	10.1	2	48	4
56	2	1	1	13	20	20	40	-2	-5.5	1	44	1
57	2	7	7	10	20	20	40	-1	16.9	2	92	1
58	5	9	9	13	20	20	80	2	20	2	28	1
59	4	6	6	13	20	20	60	1	20	2	77	1
60	4	6	6	13	20	20	60	1	20	1	78	1
61	4	12	12	13	20	20	80	-1	5.6	2	55	1
62	2	1	1	13	20	20	20	-1	20	1	78	1
63	4	2	2	13	20	20	60	1	20	2	51	4
64	6	11	11	14	20	20	100	3	20	1	63	1
65	3	11	11	13	20	20	60	-1	9	2	32	1
66	2	8	8	14	20	20	40	1	21.5	2	54	1
67	2	3	3	13	20	20	20	-1	20	1	3	1
68	3	5	5	14	20	20	40	1	20	1	64	1
69	5	1	2	14	20	20	100	-2	0	2	0.3	3
70	2	7	7	14	20	29	40	-1	17	2	44	3
71	1	9	9	7	20	20	20	-1	20	1	27	1
72	2	11	11	10	20	20	40	1	20	1	7	3
73	2	11	11	10	20	20	40	1	20	1	15	3
74	7	12	12	10	20	20	140	4	20	1	21	3

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Inside Part 1 Max Temp	Min Temp	ADD Score	RLDV	Aver Temp	Sex	Age	Pop Group
75	2	11	11	7	20	20	40	1	20	1	51	1
76	2	10	10	10	20	20	40	1	20	2	56	1
77	2	6	6	7	20	20	40	1	20	1	66	1
78	2	8	8	7	20	20	40	1	20	2	28	1
79	3	5	5	7	20	20	60	1	20	2	72	1
80	1	10	10	13	20	20	20	-1	20	1	31	1
81	1	11	11	13	20	20	20	-1	20	2	53	1
82	1	2	2	12	20	20	20	-1	20	1	28	3
83	1	11	11	12	20	20	20	-1	20	1	46	3
84	2	10	10	8	20	20	40	1	20	1	59	1
85	1	8	8	8	20	20	20	-1	20	1	45	1
86	2	2	2	8	20	20	40	1	20	1	36	1
87	5	4	4	8	20	20	100	3	20	1	47	1
88	1	7	7	8	20	20	20	-1	20	2	57	1
89	2	9	9	8	20	20	40	1	20	1	36	7
90	3	10	10	8	20	20	60	1	20	1	42	1
91	1	1	1	8	20	20	20	-1	20	1	31	1
92	1	8	8	8	20	20	20	-1	20	2	90	1
93	1	3	3	8	20	20	20	-1	20	1	49	1
94	1	4	4	8	20	20	20	-1	20	1	67	1
95	2	4	4	8	20	20	40	1	20	1	57	1
96	1	8	8	8	20	20	200	6	200	1	37	3
97	2	8	8	8	20	20	20	-1	20	1	48	1
98	2	8	8	8	20	20	40	1	20	1	51	1
99	2	6	6	8	20	20	40	1	20	2	29	1
100	1	6	6	8	20	20	20	-1	20	1	45	1
101	1	6	6	8	20	20	20	-1	20	2	51	5
102	2	7	7	8	20	20	20	-1	20	1	50	1
103	1	6	6	8	20	20	20	-1	20	1	33	1
104	2	7	7	8	20	20	40	1	20	1	55	1
105	1	7	7	8	20	20	20	-1	20	1	25	1
106	1	7	7	8	20	20	20	-1	20	1	10	4
107	1	7	7	8	20	20	20	-1	20	1	67	1
108	1	8	8	8	20	20	20	-1	20	1	26	3
109	1	8	8	8	20	20	20	-1	20	1	60	1
110	1	8	8	8	20	20	20	-1	20	1	32	1
111	1	9	9	8	20	20	20	-1	20	1	32	1
112	3	9	9	8	20	20	60	1	20	1	50	1
113	3	9	9	8	20	20	60	1	20	2	44	1

					Inside Part 1								
Case 1	**PMI DAYS**	**Month Missing**	**Month Located**	**Ecozone**	**Max Temp**	**Min Temp**	**ADD Score**	**RLDV**	**Aver Temp**	**Sex**	**Age**	**Pop Group**
114	2	9	9	8	20	20	40	1	20	1	69	1
115	2	9	9	8	20	20	40	1	20	2	48	3
116	1	9	9	8	20	20	20	-1	20	1	51	1
117	1	9	9	8	20	20	20	-1	20	2	70	1
118	1	9	9	8	20	20	20	-1	20	1	54	1
119	2	10	10	8	20	20	40	1	20	2	48	1
120	1	10	10	8	20	20	20	-1	20	2	22	1
121	2	7	7	8	20	20	40	1	20	2	45	1
122	1	6	6	8	20	20	20	-1	0	1	46	1
123	3	6	6	8	20	20	60	1	20	1	35	1
124	2	6	6	8	20	20	40	1	20	2	36	1
125	1	6	6	8	20	20	20	-1	20	1	55	1
126	5	6	6	8	20	20	100	6	20	2	47	3
127	1	6	6	8	20	20	20	-1	20	1	17	1
128	2	5	5	8	20	20	40	1	20	1	50	1
129	5	5	5	8	20	20	100	6	20	1	37	1
130	2	5	5	8	20	20	40	1	20	2	26	1
131	2	5	5	8	20	20	40	1	20	1	43	1
132	4	4	4	8	20	20	80	2	20	2	40	4
133	2	4	4	8	20	20	40	1	20	1	53	1
134	2	4	4	8	20	20	40	1	20	1	28	1
135	2	4	4	8	20	20	40	1	20	1	30	1
136	2	3	4	8	20	20	40	1	20	2	29	1
137	1	4	4	8	20	20	20	-1	20	2	39	1
138	1	3	3	8	20	20	20	-1	20	2	1.6	2
139	1	3	3	8	20	20	20	-1	20	1	0.3	1
140	2	3	3	8	20	20	40	1	20	2	97	1
141	2	7	7	8	20	20	40	1	20	1	0.1	1
142	2	6	6	8	20	20	40	1	20	1	85	1
143	5	9	9	13	20	20	80	1	20	1	6	1
144	5	5	6	13	20	20	80	1	20	2	46	1
145	1	5	5	8	20	20	20	-2	20	2	44	1
146	3	6	7	8	20	20	60	-1	20	2	78	1
147	3	6	7	8	20	20	60	-1	20	2	77	1
148	5	7	8	8	20	20	100	2	20	2	26	1
149	1	5	5	8	20	20	20	-2	20	2	0.1	2
150	3	6	6	8	20	20	60	-1	20	2	50	1
151	1	6	6	8	20	20	20	-2	20	1	45	1
152	8	6	6	8	20	20	160	3	20	1	55	1

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Inside Part 1 Max Temp	Min Temp	ADD Score	RLDV	Aver Temp	Sex	Age	Pop Group
153	2	9	9	8	20	20	40	-1	20	1	63	1
154	2	9	9	8	20	20	40	-1	20	1	51	1
155	3	5	5	8	20	20	60	-1	20	1	44	1
156	16	11	12	13	20	20	320	-1	3.05	2	62	1
157	5	9	9	13	20	20	80	-1	20	1	12	1
158	5	9	9	13	20	20	80	-1	20	1	9	1
159	5	9	9	13	20	20	80	-1	20	2	2	1
160	3	8	8	7	20	20	60	-1	20	2	34	1
161	2	11	11	12	20	20	40	-1	20	2	36	1
162	24	1	2	8	20	20	480	3	20	1	51	1
163	1	4	4	8	20	20	20	-1	20	1	89	1
164	5	7	7	8	20	20	100	-1	20	1	22	1
165	11	7	8	8	20	20	220	1	20	2	67	1
166	4	9	10	8	20	20	80	-1	20	1	45	1
167	5	10	10	8	20	20	100	-1	20	1	54	1
168	4	5	5	8	20	20	80	-1	20	1	27	5
169	6	6	6	8	20	20	120	1	20	1	59	1
170	3	9	9	13	20	20	40	-1	20	2	27	1
171	7	9	9	8	20	20	140	-1	20	1	55	1
172	31	4	5	8	20	20	620	2	20	1	67	1
173	4	4	4	8	20	20	80	-1	20	1	49	1
174	4	6	6	8	20	20	80	-1	20	1	42	1
175	16	1	1	8	20	20	320	1	20	1	42	1
177	15	4	5	13	20	20	280	-1	20	1	71	1
178	13	4	4	13	20	20	240	-1	20	2	30	3
179	62	8	10	8	20	20	1240	1	20	1	65	1
180	18	7	7	8	20	20	360	-1	20	1	44	1
181	6	11	12	8	20	20	120	-1	20	1	50	1
182	85	12	3	8	20	20	1700	1	20	1	48	1
183	21	8	8	8	20	20	420	-1	20	2	53	1
184	40	7	9	8	20	20	800	-1	20	2	61	1
185	9	3	4	8	20	20	180	-1	20	1	56	1
186	26	6	6	8	20	20	520	-1	20	1	61	1
187	23	6	6	8	20	20	460	-1	20	1	54	1
188	15	7	7	8	20	20	300	-1	20	1	48	7
189	22	7	8	8	20	20	440	-1	20	1	58	1
190	12	4	4	8	20	20	240	-1	20	1	80	1
191	10	7	7	8	20	20	200	0	20.6	1	46	1

Inside Part 2													
Case 2	**Alcohol**	**Urban/rural**	**MOD**	**type of trauma**	**# of Blows**	**Blood loss**	**body disposal**	**Clothing**	**Shroud**	**Insects**	**decomp score**	**Primary**	**Secondary**
1	2	1	1	3	4	0	1	1	2	0	0	0	0
2	1	1	1	3	6	2	1	1	1	0	0	0	0
3	1	1	1	3	1	2	3	2	1	0	0	0	0
4	1	1	1	3	8	2	1	1	1	0	0	0	0
5	1	1	3	6	0	0	1	1	1	0	0	0	0
6	2	1	1	2	5	4	1	3	1	0	0	0	0
7	3	1	1	5	0	0	1	4	1	0	0	0	0
8	3	1	1	2	6	4	1	1	1	0	0	0	0
9	3	1	1	1	1	2	1	4	2	0	0	0	0
10	3	1	3	1	1	2	1	3	1	0	0	0	0
11	3	1	1	1	1	2	1	1	2	0	0	0	0
12	3	1	3	1	1	2	1	1	1	0	0	0	0
13	2	1	1	3	10	3	1	1	1	0	0	0	0
14	2	1	1	2	10	3	1	3	1	0	0	0	0
15	2	1	1	2	1	4	1	1	1	0	0	0	0
16	3	1	1	1	1	2	1	1	1	0	0	0	0
17	3	1	1	4	1	1	1	1	2	0	0	0	0
18	3	1	1	2	10	3	1	1	1	0	0	0	0
19	3	1	1	3	10	1	2	3	1	0	0	0	0
20	2	1	1	2	10	4	1	4	1	0	0	0	0
21	3	2	1	2	10	4	1	4	2	0	0	0	0
22	3	1	1	1	1	2	1	1	1	0	0	0	0
23	3	1	1	2	7	2	1	1	1	0	0	0	0
24	3	1	1	1	1	1	1	1	1	0	0	0	0
25	3	1	3	1	1	3	1	1	1	0	0	0	0
26	1	1	1	2	2	2	1	3	1	0	0	0	0
27	2	1	1	2	2	2	1	4	1	0	0	0	0
28	1	1	1	1	1	2	1	3	1	0	0	0	0
29	3	1	1	1	1	2	1	1	1	0	0	0	0
30	1	1	1	2	1	2	1	1	1	0	0	0	0
31	3	1	1	2	4	3	1	1	1	0	0	0	0
32	3	1	1	1	3	2	2	4	3	0	0	0	0
33	2	2	1	1	1	1	1	1	1	0	0	0	0
34	1	1	1	3	1	1	1	3	1	0	0	0	0
35	3	1	4	5	0	0	1	4	1	0	0	0	0
36	1	1	2	5	0	0	1	4	2	0	0	0	0
37	2	1	2	7	0	0	1	3	1	0	0	0	0
38	1	1	2	7	0	0	1	1	1	0	0	0	0
39	2	1	3	7	0	0	1	1	1	0	0	0	0

Inside Part 2

Case 2	Alcohol	Urban/rural	MOD	type of trauma	Number of Blows	Blood loss	body disposal	Clothing	Shroud	Insects	decomp score	Primary	Secondary
40	1	1	2	7	0	0	1	3	1	0	0	0	0
41	1	1	3	4	0	0	1	1	1	0	0	0	0
42	1	1	3	2	3	4	1	4	1	0	0	0	0
43	2	1	2	7	0	0	1	3	1	0	0	0	0
44	1	1	2	7	0	0	1	3	1	0	0	0	0
45	2	1	4	7	0	0	1	1	1	0	0	0	0
46	1	1	2	7	0	0	1	3	1	0	0	0	0
47	1	1	2	7	0	0	1	3	1	0	0	0	0
48	1	1	1	3	4	1	1	3	1	0	0	0	0
49	1	1	2	7	0	0	1	3	1	0	0	0	0
50	2	1	2	7	0	1	1	3	1	0	0	0	0
51	1	1	3	4	0	2	1	3	1	0	0	0	0
52	1	1	3	4	0	0	1	3	1	0	0	0	0
53	3	1	1	2	10	2	1	3	1	0	0	0	0
54	1	2	3	4	0	0	1	1	1	0	0	0	0
55	1	1	2	7	0	0	0	4	2	0	1	1	0
56	2	1	5	7	0	0	0	1	2	0	1	0	0
57	1	1	1	2	3	2	1	2	1	0	1	0	0
58	1	1	1	3	2	2	1	3	1	0	1	0	0
59	1	1	1	6	0	0	1	1	2	0	1	0	0
60	1	1	3	6	0	0	1	1	2	0	1	0	0
61	1	1	1	3	4	1	2	1	4	0	1	0	0
62	1	1	1	3	3	2	1	1	1	0	1	0	0
63	1	1	1	3	8	2	2	1	2	0	1	0	0
64	1	1	1	2	3	2	1	3	1	0	1	0	0
65	1	1	1	4	0	0	1	1	1	0	1	0	0
66	1	2	1	1	0	1	1	1	1	0	1	0	0
67	3	1	1	5	0	0	1	4	1	0	1	0	0
68	2	1	1	2	10	3	1	1	1	0	1	0	0
69	1	1	1	3	4	0	1	1	1	0	1	3	0
70	2	1	1	2	1	2	1	1	1	0	1	0	0
71	2	1	1	1	1	3	1	1	1	0	1	0	0
72	3	1	1	1	1	2	1	1	1	0	1	0	0
73	3	1	1	1	2	2	1	3	2	0	1	0	0
74	3	1	1	1	2	2	1	1	1	0	1	0	0
75	3	1	1	3	10	1	2	2	1	0	1	0	0
76	3	1	1	1	3	2	1	1	1	0	1	0	0
77		1	1	3	10	1	1	1	1	0	1	0	0
78	3	1	1	1	1	2	1	4	2	0	1	0	0

Inside Part 2													
Case 2	**Alcohol**	**Urban/rural**	**MOD**	**type of trauma**	**Number of Blows**	**Blood loss**	**body disposal**	**Clothing**	**Shroud**	**Insects**	**decomp score**	**Primary**	**Secondary**
79	2	1	1	3	5	2	1	3	1	0	1	0	0
80	2	1	1	2	2	2	1	1	1	0	1	0	0
81	3	1	1	3	10	1	1	1	1	0	1	0	0
82	2	1	1	2	1	2	1	1	1	0	1	0	0
83	2	1	1	3	10	2	1	1	1	0	1	0	0
84	1	1	3	4	0	1	1	1	1	0	1	0	0
85	2	1	2	7	0	0	1	1	1	0	1	0	0
86	1	1	2	7	0	0	1	1	1	0	1	1	0
87	3	1	2	7	0	0	1	1	1	0	1	0	0
88	1	1	3	5	0	0	1	1	4	0	1	0	0
89	1	1	4	3	1	0	1	1	1	0	1	0	0
90	1	1	2	7	0	0	1	2	1	0	1	0	0
91	2	1	2	7	0	0	1	1	1	0	1	0	0
92	1	1	4	4	0	0	1	3	1	0	1	0	0
93	1	1	3	4	0	0	1	3	1	0	1	0	0
94	1	1	4	3	1	0	1	1	1	0	1	0	0
95	2	1	3	4	0	0	1	1	1	0	1	0	0
96	1	1	3	5	0	0	1	1	1	0	1	0	0
97	2	1	3	5	0	0	1	3	1	0	1	0	0
98	1	1	4	7	0	0	1	3	1	0	1	0	0
99	1	1	2	7	0	0	1	3	1	0	1	0	0
100	2	1	3	5	0	0	1	1	1	0	1	0	0
101	1	1	3	4	0	0	1	1	1	0	1	0	0
102	1	1	2	7	0	0	1	1	1	0	1	0	0
103	1	1	4	7	0	0	1	1	1	0	1	0	0
104	1	1	3	4	0	0	1	1	1	0	1	0	0
105	2	1	3	1	1	2	1	3	1	0	1	0	0
104	1	1	3	2	2	3	1	3	1	0	1	0	0
105	1	1	4	7	0	0	1	3	1	0	1	0	0
106	1	1	2	7	0	0	1	1	1	0	1	0	0
107	1	1	4	7	0	0	1	3	1	0	1	0	0
108	2	1	4	5	0	0	1	1	1	0	1	0	0
109	1	1	3	4	0	0	1	1	1	0	1	0	0
110	2	1	3	4	0	0	1	1	1	0	1	0	0
111	1	1	4	7	0	0	1	3	1	0	1	0	0
112	1	1	2	7	0	0	1	1	1	0	1	0	0

Inside Part 2													
Case 2	**Alcohol**	**Urban/rural**	**MOD**	**type of trauma**	**Number of Blows**	**Blood loss**	**body disposal**	**Clothing**	**Shroud**	**Insects**	**decomp score**	**Primary**	**Secondary**
113	1	1	3	7	0	0	1	3	2	0	1	0	0
114	1	1	3	1	1	2	1	1	1	0	1	0	0
115	1	1	4	7	0	0	1	3	1	0	1	0	0
116	1	1	3	4	0	0	1	1	1	0	1	0	0
117	1	1	4	3	1	2	1	1	1	0	1	0	0
118	1	1	3	4	0	0	1	1	1	0	1	0	0
119	2	1	4	7	0	0	1	4	1	0	1	0	0
120	1	1	4	7	0	0	1	3	1	0	1	0	0
121	2	1	3	7	0	0	1	1	1	0	1	0	0
122	2	1	3	4	0	0	1	3	1	0	1	0	0
123	1	1	4	7	0	0	1	3	1	0	1	0	0
124	2	1	3	4	0	0	1	1	1	0	1	0	0
125	1	1	3	2	2	2	1	1	1	0	1	0	0
126	1	1	4	7	0	0	1	4	1	0	1	0	0
127	1	1	4	7	0	0	1	1	1	0	1	0	0
128	1	1	3	6	0	0	1	4	1	0	1	0	0
129	2	1	3	1	1	3	1	1	1	0	1	0	0
130	1	1	3	4	0	0	1	1	1	0	1	0	0
131	1	1	2	7	0	0	1	3	1	0	1	0	0
132	1	1	3	4	0	0	1	1	1	0	1	0	0
133	1	1	3	5	0	0	1	4	1	0	1	0	0
134	1	1	4	7	0	0	1	1	1	0	1	0	0
135	1	1	4	7	0	0	1	1	1	0	1	0	0
136	1	1	4	7	0	0	1	1	1	0	1	0	0
137	1	1	2	7	0	0	1	1	2	0	1	0	0
138	1	1	4	4	0	0	1	4	2	0	1	0	0
139	1	1	4	5	0	0	1	4	2	0	1	0	0
140	1	1	2	7	0	0	1	4	1	0	1	0	0
141	1	1	2	7	0	0	1	4	1	0	1	0	0
142	1	1	4	3	0	0	1	3	1	0	1	0	0
143	1	1	1	3	2	2	1	3	1	0	2	0	0
144	1	1	1	2	5	2	1	2	2	0	2	0	0
145	2	1	3	7	0	0	1	1	2	0	2	0	0
146	1	1	1	3	10	2	1	3	2	0	2	0	0
147	1	1	1	3	10	2	1	3	4	0	2	0	0
148	1	1	2	5	0	0	1	3	2	1	2	1	0
149	1	1	4	5	0	0	1	3	2	0	2	2	0

Inside Part 2

Case 2	Alcohol	Urban/rural	MOD	type of trauma	Number of Blows	Blood loss	body disposal	Clothing	Shroud	Insects	decomp score	Primary	Secondary
150	1	1	3	7	0	0	1	3	1	0	2	0	0
151	1	1	3	7	0	0	1	4	1	0	2	0	0
152	1	1	4	5	0	0	1	3	1	0	2	0	0
153	1	1	4	7	0	0	1	1	1	1	2	0	0
154	2	1	4	6	0	1	1	3	1	0	2	0	0
155	1	1	4	6	0	0	1	3	1	0	2	0	0
156	1	1	2	7	0	3	1	3	1	0	3	1	0
157	1	1	1	3	2	2	1	3	2	0	3	0	0
158	1	1	1	3	2	2	1	4	2	0	3	0	0
159	1	1	1	3	2	2	1	3	2	0	3	0	0
160	3	2	1	2	8	3	2	1	4	0	3	0	0
161	3	1	1	4	0	0	2	4	2	0	3	0	0
162	2	1	3	7	0	0	1	4	2	0	3	2	0
163	1	1	3	4	0	0	1	1	1	0	3	0	0
164	1	1	3	4	0	0	1	3	1	0	3	0	0
165	1	1	2	7	0	0	1	3	1	0	3	0	1
166	2	1	4	7	0	0	1	4	1	0	3	0	0
167	1	1	3	1	1	3	1	1	1	0	3	0	0
168	1	1	3	4	0	0	1	1	1	0	3	0	0
169	1	1	3	4	0	0	1	1	1	0	3	0	1
170	2	1	1	2	9	1	1	3	1	0	4	0	0
171	2	1	5	7	0	0	1	4	2	2	4	2	0
172	1	1	2	7	0	0	1	4	1	0	4	2	0
173	1	1	4	7	0	0	1	1	1	0	4	0	2
174	1	1	3	2	0	4	1	3	1	2	4	0	1
175	1	1	4	7	0	0	1	4	1	0	4	0	0
177	2	1	1	3	10	2	1	3	1	2	5	0	0
178	2	1	1	4	1	2	1	4	2	2	5	0	0
179	1	1	2	7	0	0	1	4	1	3	5	3	0
180	2	1	4	7	0	0	1	1	1	0	5	0	0
181	1	1	2	7	0	0	1	3	1	0	5	0	0
182	1	1	2	7	0	0	1	3	1	0	5	3	0
183	1	1	2	7	0	0	1	4	1	2	5	3	0
184	1	1	2	7	0	0	1	3	1	2	5	2	0
185	1	1	2	7	0	0	1	3	1	0	5	1	0
186	2	1	3	7	0	0	1	1	1	2	5	0	0
187	1	1	2	7	0	0	1	3	1	0	5	0	0
188	1	1	2	7	0	0	1	1	1	3	5	0	0
189	2	1	2	7	0	0	1	3	1	3	5	0	3
190	1	1	2	7	0	0	1	3	1	2	5	0	0
191	1	1	2	7	0	0	1	3	1	0	6	3	0

Case 1	PMI DAYS	Month Missing	Month Located	Ecozone	Ecodistrict	Total Precip	Water Part 1			RLDV	Aver Temp	1st 30 days Aver	Sex	Age	Appearance	Build	Illness
							Max Temp	Min Temp	ADD Score								
1	3	9	9	8	545	0	25.6	11.2	55.2	-1	18.4	0	1	50	3	2	1
2	1	5	5	8	545	0	29.8	16.8	23.3	-1	23.3	0	1	24	2	2	1
3	2	1	1	8	545	6	-9.7	-22.7	0	-1	-15.5	0	1	51	1	2	1
4	24	2	3	14	982	2.5	9.6	-23	4.3	-2	0	0	2	21	1	2	1
5	14	10	11	14	1007	14	12.2	-1.5	88	2	6	0	1	25	1	2	1
6	2	4	4	8	545	15.4	16.4	2.3	12	-1	6	0	1	26	1	3	1
7	2	4	4	8	545	0	20	20	40	-1	20	0	1	53	1	2	2
8	3	9	9	8	545	0	20	20	60	1	20	0	1	23	4	2	1
9	36	7	8	13	959	0.2	29.2	11.7	301.5	1	8.6	0	2	18	1	1	3
10	35	1	2	21	957	275.8	9.4	-9.8	218.5	1	6.4	0	1	42	1	2	2
11	10	7	7	9	702	60.4	26.2	9.3	193.9	-2	21.5	0	2	26	3	2	1
12	11	12	12	13	959	27.6	11.6	-3.6	49.2	-2	4.9	0	1	17	6	1	1
13	36	7	8	13	959	0.2	29.2	11.7	301.5	1	8.6	0	2	18	1	1	1
14	23	10	10	13	959	94	16.5	1.7	226.8	-1	10.4	0	2	10	1	2	1
15	24	9	9	13	959	40.2	22.5	4.9	320.2	-1	13.9	0	1	34	5	3	1
16	24	5	5	14	1007	2	19.1	1.6	363	-1	15	0	1	31	3	2	3
17	115	2	6	8	545	218.2	35.8	-11.7	1349.8	2	13.2	0	2	30	1	3	1
18	152	1	6	8	545	275.6	35.8	-23.3	1144.3	1	7.5	-6	2	39	1	3	1
19	32	5	6	21	957	85	23.4	6.9	478.2	2	15.4	0	2	34	4	2	2
20	47	3	5	10	849	68	21.2	-18.1	194	-1	4	3	1	51	1	3	2
21	150	12	5	8	545	270.2	26.1	-26.3	415.2	1	-1	-5	1	40	1	2	3
22	5	8	8	8	545	0.4	28.9	9.3	102.8	-2	20.5	0	1	57	1	3	2
23	121	11	3	8	545	231	17.5	-23.3	131	-1	-1	5	1	31	1	3	1
24	16	1	1	8	545	0	20	20	320	1	20	0	1	42	1	2	1
25	47	6	8	21	957	47.4	27.5	11.3	852.8	0	18.5	18	1	37	5	2	2
26	190	9	4	14	1003	163.6	28.5	-15.5	833.6	-1	5.4	9	1	7	1	1	1
27	321	10	12	12	950	1146	39.4	-18.7	3907.2	1	8.2	7.5	1	28	1	2	3

Water Part 2

Case 2	Alcohol	Indoor/outdoor	Urban	Water type	Water flow	Submersion	MOD	Type of trauma	# of Blows	Clothing	Shroud	Objects on body	Scavenger	Insects	Decomp Score	Primary	Secondary
1	2	2	0	2	1	2	4	5	0	4	1	0	0	0	0	0	0
2	1	2	0	2	1	3	4	5	0	2	1	0	0	0	0	0	0
3	1	2	6	2	1	3	4	5	0	4	1	0	0	0	0	0	0
4	2	2	0	2	1	3	1	6	0	2	1	0	0	0	1	0	0
5	2	2	0	2	1	3	1	3	1	2	3	0	0	0	1	0	0
6	1	2	0	2	1	3	4	5	0	4	1	2	0	0	1	0	0
7	1	1	8	2	1	3	3	5	0	1	1	0	0	0	1	0	0
8	2	1	8	2	2	3	3	5	0	1	1	0	0	0	1	0	0
9	1	2	7	2	2	3	1	3	8	1	1	0	0	0	2	7	0
10	1	2	0	1	1	1	3	5	0	4	1	0	0	0	2	0	0
11	2	2	0	2	2	2	1	7	0	1	1	0	0	0	2	7	2
12	2	2	7	2	1	1	1	5	10	2	1	3	0	0	2	1	0
13	1	2	0	2	2	3	1	2	8	1	1	0	0	0	2	0	0
14	1	2	0	2	2	3	1	4	0	1	2	0	1	0	3	1	0
15	2	2	0	2	2	3	1	1	1	1	1	0	0	0	3	0	0
16	3	2	0	2	1	3	1	3	3	4	1	0	0	0	3	0	0
17	1	2	0	2	1	1	3	7	0	4	1	0	2	0	3	0	0
18	1	2	6	2	1	2	4	5	0	4	1	0	2	0	3	0	0
19	1	2	0	1	1	1	3	5	0	4	1	0	0	0	4	0	0
20	1	2	0	2	1	1	3	5	0	4	1	0	0	0	4	2	0
21	3	2	0	2	1	1	3	5	0	1	1	0	0	0	4	0	0
22	1	2	0	2	1	1	3	5	0	2	1	0	0	0	4	0	0
23	1	2	0	2	1	2	3	5	0	4	1	0	1	0	4	0	1
24	1	1	8	2	2	2	4	7	0	1	1	0	0	0	4	0	0
25	1	2	0	1	1	1	3	5	0	2	1	0	2	2	5	3	13
26	3	2	0	2	1	3	1	5	0	4	1	0	0	0	6	7	0
27	3	2	0	2	1	3	4	5	0	4	2	3	0	0	6	15	0