Estimating Postmortem Intervals of Human Remains Recovered in Mid-Western Waterways: A Test of Terrestrial and Aquatic Body Scoring Methods

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I am submitting herewith a thesis written by Amanda Rose Fink entitled "Estimating Postmortem Intervals of Human Remains Recovered in Mid-Western Waterways: A Test of Terrestrial and Aquatic Body Scoring Methods." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Lee Meadows Jantz, Major Professor

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Estimating Postmortem Intervals of Human Remains Recovered in Mid-Western Waterways: A Test of Terrestrial and Aquatic Body Scoring Methods

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ABSTRACT

In attempt to determine postmortem intervals (PMI), forensic investigators often rely on observed amounts of postmortem taphonomic alterations of the human body. Research has been conducted in an attempt to understand and predict the sequence and rate of human decomposition using total body scoring methods as well as accumulated degree days (ADD) (Megyesi et al. 2005). While most research focuses on methods of decomposition scoring in terrestrial environments, Heaton et al. (2010) devised a method to aid in the prediction of PMI and postmortem submersion intervals (PMSI) in an aqueous environment. Using 73 forensic cases collected from the Hennepin County, MN, Medical Examiner’s Office, La Crosse, WI, Medical Examiner’s Office, and the Manitowoc County, WI, Medical Examiner’s Office, this study demonstrates that aquatic taphonomic alterations do not always occur in a sequential pattern due to a plethora of variables, such as water temperature. The data were split into three categories according to known ADD. Using both the Megyesi et al. (2005) and the Heaton et al. (2010) decomposition scoring methods, cold water submersion of a human body can produce varied results and the inability to accurately predict PMI and PMSI. Those forensic cases with the shortest PMSI also show a low accuracy rate of predicting PMSI. Both the Megyesi et al. (2005) and the Heaton et al. (2010) total scoring methods resulted in more accurate PMSI prediction for those cases with ADDs between 26°C and 99°C. This study demonstrates the demand for more accurate decompositional scoring methods and the need for
further exploration into the study of the effects of cold-water temperatures on the
taphonomic process of the human body.
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CHAPTER 1

INTRODUCTION

Worldwide an estimated 372,000 deaths occur annually as a consequence of drowning (World Health Organization 2016). Frequently deceased individuals are found floating in bodies of water, or searched for within bodies of water when reported missing. Autopsies are conducted on drowning victims in an attempt to understand the cause and manner of death of waterlogged bodies, while forensic scientists utilize an array of qualitative factors to help determine postmortem intervals (PMI) and postmortem submersion intervals (PMSI) (Mateus and Vieira 2014; Papadodima et al. 2010). Predicting time since death is important in all circumstances of death, including drowning. With an accurate estimation of PMI investigators can narrow the missing persons list, exclude suspects in homicide cases, and identify the decedent. Anthropological studies have significantly advanced this field in recent years utilizing outdoor research facilities at the University of Tennessee, Knoxville, Texas State, Sam Houston State, Southern Illinois University, Colorado Mesa University, and Western Carolina University to better understand postmortem changes of the human body.

The use of human donors has allowed advances in research in the field of anthropology and human decomposition. This research has helped to create predicted rates and sequences of human decomposition in specific environments (Megyesi et al. 2005 and Heaton et al. 2010). Most of this research has focused
on different types of terrestrial environments. The University of Tennessee Knoxville’s Anthropology Research Facility, founded by William M. Bass, spearheaded research of postmortem decomposition changes using donors beginning in the 1980’s (Rodriguez and Bass 1983). Since that time, five other facilities across the nation have conducted research, significantly adding to the literature of PMI and decomposition studies (Klein 2015).

One type of environment that is not thoroughly understood in the anthropological literature analyzing human decomposition is the aqueous environment. The effects that a water environment has on human decomposition have generated a gap in the literature due to several reasons. Creating experimental bodies of water to mimic lakes, rivers, or streams is prohibitive on many levels. Locating and securing a location to construct a mock waterway can become an overwhelming task. Further simulating fluctuating water temperatures, current, depth, and PH level is virtually unmanageable. The cost of creating a mock waterway incorporating the plethora of variables, including current, fluctuating temperatures, aquatic animals, insects, etc. are insurmountable. In addition, ethical restrictions prohibit the use of human tissue in authentic waterways, forcing many researchers to utilize Sus scrofa as human analogues (Anderson 2010; Forbes et al. 2010; Humphreys at al. 2013; Michaud and Moreau 2011). Due to the high cost and unmanageable task of mimicking waterways, researchers often rely on actual waterways to conduct studies (Anderson 2010; De Donno et al. 2014; Forbes et al. 2010; Haglund 1993;
The purpose of this study is to attempt to fill this gap in the literature by using forensic case studies and medical examiner records to generate information on how water affects the decomposition process, allowing or inhibiting forensic scientists to predict accurate PMIs and PMSIs.

This study focuses on submerged cases from the Midwestern United States involving a variety of different water temperatures. Known PMIs from medical examiner’s and police reports are used to understand the effects of water on the decomposition process. In addition, factors relating to the decomposition process, such as discoloration and skin slippage, as well as environmental factors, such as water temperature, were collected from autopsy reports and medical examiner/coroner reports. The generally accepted model incorporates only temperatures as a variable following a simple principle that colder water temperatures drastically slow the decomposition process, while warmer water temperatures allow for a regular and predicted rate of human decomposition (Heaton et al. 2010). Efforts have been conducted to formulate and verify a quantitative approach to demonstrate descriptive stages of decomposition (De Donno et al. 2014; Heaton et al. 2010; Megyesi et al. 2005; Michaud and Moreau 2011). However, a need has been expressed for validation studies of the estimation of PMSI estimates in aqueous environments utilizing accumulated degree days, otherwise known as the amount of thermal heat required to create decomposition changes (De Donno et al. 2014; Heaton et al. 2010; Megyesi et al. 2005; Michaud and Moreau 2011).
2010). It is important to understand the effects water has on the decomposition process in order to aid law enforcement and medico-legal death investigators in their prediction of PMIs and PMSIs. Accurate estimations of time since death and time since body submersion can expedite the process of decedent identification, as well as suspect identification in homicide cases.

Hypotheses

This study specifically looks to determine whether it is possible to assign accurate PMIs due to the effects water has on the decomposition process of waterlogged bodies through the following questions:

1.) How does water submersion affect the expression of decomposition and the rate of decomposition?

1A.) Is there a pattern of the decomposition process in an aqueous environment?

2.) How does water submersion impact PMSI estimates in waterlogged bodies?

2A.) Can Total Aquatic Decomposition Score (Heaton et al. 2010) be used to predict accumulated degree days (ADD) and PMSI in cold water cases and cases with short PMSIs?

2B.) Can Total Body Score (Megyesi et al. 2005) be used predict ADD and PMSI in waterlogged bodies?
In more recent years research on aquatic human decomposition has begun to focus on approaches of estimating postmortem submersion intervals by utilizing methods involving accumulated degree days (De Donno et al. 2014; Heaton et al. 2010; Humphreys et al. 2013; Mateus and Vieira 2014). Perhaps one of the most well known methods to estimate postmortem intervals based on qualitative visual assessments of decomposition is by Megyesi et al. (2005). Megyesi et al. (2005) included a total of 68 human remains cases in the United States in various outdoor and indoor settings to score decomposition. Using a point based scoring system, body areas were individually assessed and assigned a score according to the stage of decomposition to which the area has progressed. While this particular system is specialized to predict PMIs in specific terrestrial environments, Heaton et al. (2010) have provided a revised method that fits an aquatic environment. The Heaton et al. (2010) study included a total of 187 forensic drowning case files from rivers in Scotland and northwest England. Heaton et al. (2010) excluded cases with an ADD<10 due to the classification of the remains as fresh decomposition. According to Heaton et al. (2010), bodies in a fresh state can be assessed to determine PMIs using conventional methods.

Both point based scoring systems for decomposition by Megyesi et al. (2005) and Heaton et al. (2010) utilize ADD. ADD is the amount of heat energy
that is necessary to continue the decomposition process (Megyesi et al. 2005). Daily temperature averages are summed for each day of the PMI resulting in a final ADD. Using ADD in combination with a point based scoring systems allows the use of temperatures to estimate unknown PMIs or PMSIs in the case of an aqueous environment. For example, using the Heaton et al. (2010) point-based scoring system (TADS), a body with a total aquatic decomposition score of 9 would estimate the individual had been submerged for a total of 43.01°C ADD according to the equation TADS=−3.706+7.778*LOG ADD. Utilizing water temperature records, it could be determined that the decedent had been submerged for four days at an average water temperature of 10.75°C. Because decomposition is temperature dependent these models utilize expressions of decomposition to predict time since death or submersion. Bodies in terrestrial environments and aqueous environments are subjected to similar scoring methods utilizing ADD. Total body score (TBS) and total aquatic decomposition score (TADS) are summed from decomposition scores of the head, trunk, and limbs, and an outcome of estimated ADD is created. Since the time of discovery of human remains is always known, one can use the calculated ADD and actual ambient temperature data for each day to calculate an estimated PMI or PMSI.

Methods of decomposition scoring to predict PMIs continue to be scrutinized due to small sample sizes, the utilization of pigs as human analogs, and the plethora of environmental factors that can affect the rate of decomposition (Bass 1997; De Donno et al. 2014; Humphreys et al. 2013;
Suckling et al. 2016). This chapter will discuss the process of human decomposition, effects of water submersion on a human body and factors affecting the rate of human decomposition in water, methods used to estimate PMSIs, and the concerns forensic investigators face when determining PMSIs.

**Postmortem Changes and Human Decomposition**

Forensic anthropologists are becoming more involved in the process of death investigation (Marks et al. 2009). While forensic anthropologists are highly specialized in skeletal examination, the progression from a fresh corpse to skeletal material continues to be a critical process in death evaluations and an interest to anthropologists. Working in tandem with forensic scientists, such as pathologists and entomologists, the study of forensic anthropology can not only assist in determining the manner of death, but also can provide an estimated time interval since a victim’s death. An anthropologist can attempt to estimate PMIs through studies of the human taphonomic process, which can be broken down into several methodical and well-documented steps (Marks et al. 2009).

Megyesi et al. (2005) approached decomposition scoring by splitting the stages of decomposition into fresh, early decomposition, advanced decomposition, and skeletonization. The fresh stage is described as no change or discoloration to the body (Megyesi et al. 2005). Early stages of decomposition include: discoloration of the skin progressing to a gray/green color, skin slippage, purge, and bloating. However, forensic scientists and death investigators look for
several other early physiological changes indicating an estimation of time since death such as pallor, rigor mortis, algor mortis, and livor mortis.

Decomposition includes internal and external processes. Internal decomposition is comprised of cell death, which can often be detected and scored externally through the presence of bloating, marbling, and color changes to the skin. The processes of internal and external decomposition which result in the reduction of human remains and can commence as quickly as 15 minutes after death occurs (Clark et al. 1997; Marks et al. 2009). The earliest postmortem change, pallor, is defined as an alteration or lightening of skin color (Clark et al. 1997). This loss of skin color is caused by a lack of oxygenated blood circulating throughout the body. Pallor is more easily detected in lighter skinned individuals, and can often be indiscernible in individuals with darker skin tones. Also occurring within the first two hours postmortem is skeletal muscle relaxation, including sphincter relaxation. Relaxation of the muscles and sphincters can lead to fecal soiling and purging of the gastric contents (Clark et al. 1997).

Other postmortem changes can be detected between two and four hours postmortem. Marks et al. (2009) explain that autolysis, the internal biochemical process of cell death, is the earliest development of decomposition. This process of cell death ultimately leads to external evidence of decomposition such as tissue necrosis, putrefaction, algor mortis, rigor mortis, and livor mortis (Amendt et al. 2010). While these postmortem processes act independently of one
another, often they occur concurrently (Clark et al. 1997; Marks et al. 2009; Prahlow 2010).

Algor mortis, defined as the cooling of the body to reach an ambient temperature, begins immediately postmortem. The deceased's body temperature will decrease, or in some cases increase, at an approximate average rate of 1.5°F each hour postmortem until the ambient temperature is reached (Amendt et al. 2010; Clark et al. 1997). However, several factors, such as body mass and ambient temperature, can affect the rate of algor mortis (Amendt et al. 2010).

Rigor mortis is defined as muscle stiffening due to autolysis of muscle cells, causing the muscle fibers to biochemically bind together (Amendt et al. 2010; Marks et al. 2009). This chemical process of muscle stiffening is often used to aid as a predictor of PMIs. Many death investigators understand the onset of rigor mortis to commence two hours after a victim’s death, become fully set around 12 hours after death, and dissipate over the next 12 hour span (Clark et al. 1997). However the rate of onset and dissipation of rigor mortis is dependent on several factors (Amendt et al. 2010; Prahlow 2010). Antemortem body temperature of the victim, as well as warm ambient temperatures, can increase the rate, onset, and dissipation of rigor mortis. Conversely, cooler ambient temperatures will decrease the rate of rigor mortis (Amendt et al. 2010; Clark et al. 1997). Often seen in drowning deaths, an increase of physical activity immediately prior to death can give rise to an immediate or increased onset of rigor mortis (Amendt et al. 2010). Adenosine triphosphate (ATP) is already
lacking in the cells due to increased of perimortem physical activity, causing an instantaneous restriction in the actin and myosin muscle fibers, resulting in a sudden or increased rate of appearance of rigor mortis (Prahlow 2010).

Livor mortis is also occurring simultaneously with algor mortis and rigor mortis. Livor mortis is defined as blood pooling due to lack of circulation throughout the deceased’s body (Amendt et al. 2010; Clark et al. 1997; Marks et al. 2009) (Figure 2.1). A lack of hemoglobin in the red blood cells causes the blood to darken starting 15 minutes postmortem. After two hours postmortem livor mortis is easily detectable on the lowest part of the body and will become fixed as body temperature continues to decrease (Amendt et al. 2010; Clark et al. 1997). Research by Henssge and Madea (2007) aims to create a more accurate model of predicting PMIs from body temperatures and observance of these early postmortem changes while considering the variable factors, such as ambient temperature.
Figure 2.1. Livor Mortis. Blood pooling due to the lack of circulation. La Crosse County Medical Examiner’s office, Chief Medical Examiner: Timothy Candahl.
As autolysis continues, cellular junctions between layers of the epidermis and the dermis begins to break down. This results in epidermal skin slippage, hair slippage and loose fingernails and toenails. Skin slippage can be detected as early as 48 hours postmortem (Clark et al. 1997). During cell autolysis cell membranes begin to deteriorate, allowing swelling of the cell. The pH of the cell lowers due to cytoplasm leaking from the cell. This decrease in pH allows enzymes to consume the cell, loosening the layers of the skin (Clark et al. 1997; Marks et al. 2009). Bullae, collections of fluid between the dermis and epidermis, can also be detected at this stage of decomposition. Slippage of the hair, nails, and skin, as well as bullae under the epidermis, can easily wipe off or become ruptured with movement of the deceased’s body (Clark et al. 1997). In extreme moist or wet environments skin can be removed in large portions (Figure 2.2). The skin of the hand can often be removed as a complete unit item, referred to as “glove formation” or “degloving” (Amendt et al. 2010; De Donno et al. 2014; Heaton et al. 2010; Humphreys et al. 2013).

The continuation of autolysis results in postmortem changes to the internal organs. The organs begin to lose their structure, resulting in a soft doughy texture. The organs eventually start to liquefy, and pathologists will often note the presence of decomposition fluid in the skull, thorax, and abdomen during autopsy. Autolysis of the red blood cells, referred to as hemolysis, can be visible superficial to the skin of the decedent. This phenomenon, often reported as
Figure 2.2. Skin slippage on the trunk and arms due to water submersion. Marbling due to deoxyhemoglobin in superficial blood vessels of the arm. La Crosse County Medical Examiner's Office, Chief Medical Examiner: Tim Candahl.
marbling is a result of the blue hue of deoxyhemoglobin in superficial blood vessels also shown in the arm in figure 2.2 (Clark et al. 1997; Prahlow 2010).

During one’s life microorganisms, such as bacteria and fungi, within the body are usually kept in check by the body’s normal immune defense systems. After death, these defense systems no longer function, allowing microorganisms to grow and consume soft tissues (Prahlow 2010). This process, referred to as putrefaction, produces gas as well as decomposition fluid.

Occurring simultaneously with autolysis, putrefaction begins its process in areas of sufficient amounts of blood. Red blood cells provide a food source for microorganisms. Therefore the products of autolysis and putrefaction, gas/bloating and decomposition fluid are not consistent throughout the deceased’s body. Bloating and fluids are often first noticed in areas of liver mortis and other highly vascularized areas. The first areas to bloat due to these processes of decomposition are the lips, face, and in males, the scrotum (Clark et al. 1997; Marks et al. 2009; Prahlow 2010). Facial bloat can be recognized in Figure 2.3.

The abdomen will begin to bloat simultaneously with or shortly after the face and lips begin to bloat between two and seven days postmortem (Galloway et al. 1989; Marks et al. 2009; Megyesi et al. 2005). Gases remain trapped within the abdomen, which can cause bloating, often engorging the abdomen to several times its original size (Amendt et al. 2010). The cecum, a structure in the left lower quadrant of the gastrointestinal tract, is a site containing many bacteria.
Figure 2.3. Facial bloat as a result of 92.22°C ADD water submergence. La Crosse County Medical Examiner’s Office, Chief Medical Examiner: Tim Candahl.
Hydrogen sulfide gas, a byproduct of bacterial metabolic processes, diffuses through soft tissues, and because the cecum is minutely deep to the skin of the abdomen putrefaction, is easily detectable in this area. A dark discoloration can be seen beneath the skin, superficial to the cecum as a result of the hydrogen sulfide gas reacting with iron, a byproduct of hemoglobin degradation. This reaction, producing a ferrous sulfide precipitate, will advance throughout the abdomen. As the biliary structures begin to decompose, additional pigments are released into the abdomen and structures of the circulatory system. The subsequent reactions create a color change progression of the body from palor, to green, purple, and reaching assorted shades of brown (Clark et al. 1997; Marks et al. 2009; Prahlow 2010).

The processes of putrefaction and autolysis eventually leads to the loss of most soft tissues indicative of the latter stages of skeletonization and bone weathering around four to six months postmortem in an arid environment (Galloway et al. 1989). Humid environments can allow for increased fly and maggot activity, allowing for the rate of decomposition to accelerate (Mann et al. 1990). The stages of decay in a normal environment are listed in Table 2.1.

Researchers must consider the multiple variables affecting decomposition in an abnormal environment. As noted, cooler ambient temperatures can retard the decomposition process, and warmer temperatures can accelerate the process (Bass 1997: Heaton et al. 2010; Mann et al. 1990). Other environmental factors affecting decomposition are aridity and humidity of the surroundings. Soft
Table 2.1. Stages of decay and associated gross morphologic changes from Marks et al. (2009)

<table>
<thead>
<tr>
<th>Stage of Decomposition</th>
<th>External Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>Algor Mortis</td>
</tr>
<tr>
<td></td>
<td>Livor Mortis</td>
</tr>
<tr>
<td></td>
<td>Rigor Mortis</td>
</tr>
<tr>
<td>Discoloration</td>
<td>Initial Skin Slippage</td>
</tr>
<tr>
<td></td>
<td>Abdominal Discoloration</td>
</tr>
<tr>
<td></td>
<td>Progressive discoloration of thorax and neck</td>
</tr>
<tr>
<td></td>
<td>Marbling</td>
</tr>
<tr>
<td>Bloating</td>
<td>Abdominal distention</td>
</tr>
<tr>
<td></td>
<td>Bloating progresses throughout the body</td>
</tr>
<tr>
<td>Skeletonization</td>
<td>Bloating completely subsided</td>
</tr>
<tr>
<td></td>
<td>Soft tissue continues to deteriorate</td>
</tr>
<tr>
<td>Skeletal Decomposition</td>
<td>All soft tissues consumed</td>
</tr>
<tr>
<td></td>
<td>Skeleton completely disarticulated</td>
</tr>
<tr>
<td></td>
<td>Cortex of bone begins to crack and age</td>
</tr>
</tbody>
</table>
tissues often dry out in arid and also hot environments resulting in mummification of the corpse (Bass 1997; Clark et al. 1997; Galloway et al. 1989). The presence of insects and animals scavenging (anthropophagy) can also accelerate the

Table 2.1. Stages of decay and associated gross morphologic changes from decomposition process (Amendt et al. 2010; Bass 1997). Other factors, such as amount of clothing as well as tautness of the garments, can also slow the rate of decomposition (Bass 1997; Prahlow 2010).

By understanding postmortem changes as a series of taphonomic modifications, anthropologists and death investigators are able to estimate a PMI range of the deceased. It is important to consider the various environmental and non-environmental variables that can alter the known sequence and rate of decomposition when making these estimations. Researchers, such as Megyesi et al. (2005) and Heaton et al. (2010), have created point based scoring systems in attempt to estimate PMIs according to sequenced postmortem taphonomic modifications. These methods are unable to take into account all of the various factors affecting decomposition. However, due to lack of a more appropriate and all-encompassing approach of scoring methods to predict PMIs, Megyesi et al. (2005) and modified versions of a total body scoring methods continue to be applied in death investigations and research.
Factors Affecting the Rate of Human Decomposition in Water

As in terrestrial decomposition, aquatic decomposition is expected to occur in a sequential progressive pattern across many types of waterways (Heaton et al. 2010). Though aquatic decomposition can be predicted in a sequential manner several factors can affect the rate of decomposition of human remains submerged in water (Haglund 1993; Prahlow 2010). Environmental and body factors can both accelerate and inhibit rates of decomposition. Environmental factors, including water temperature, depth, current, aquatic life, and obstructions or debris, can severely affect decomposition (Haglund 1993; Petrik et al. 2004). Haglund (1993) recognizes additional factors such as the presence of clothing, body size, floating or submerged position, and trauma as having decompositional influences.

It is understood that bodies submerged in water decay at a much slower rate than those in terrestrial environments. It is often estimated that decomposition occurs twice as slow in an aqueous environment in comparison to a terrestrial environment (Petrik et al. 2004; Rodriquez 1997). This is due to several different environmental factors; temperature being the most influential (Mann et al. 1990; Payne-James et al. 2011; Petrik et al. 2004; Prahlow 2010; Rodriquez 1997). Cooler temperatures can severely decelerate the rate of decomposition, partially due to a decreased amount of microbes and other aquatic life feeding on the submerged body (Cockle and Bell 2015; Petrik et al. 2004; Rodriquez 1997; Sorg et al. 1997).
Most dependent on temperature is the rate of cell autolysis, which occurs at a much slower rate in cooler temperatures, ultimately slowing the entire decomposition process (Rodriquez 1997). A slower or halted rate of cell death leads to a longer pre-bloat interval, in which the body will remain fully submerged until a sufficient amount of putrefactive gases in the gastrointestinal tract and lungs develop from cell autolysis, which may cause the body to resurface. Temperatures are generally cooler at the bottom of bodies of water, consequently prolonging the pre-bloat stage of decomposition (Rodriquez 1997). Payne and King (1972) found that each of the 11 pig specimens used in their study sank to the bottom of a water filled tank when initially placed in the water. In the summer it took two days for the specimens to bloat and float to the water's surface, while it took between two and three weeks to do so in the winter. Mateus and Vieira (2014) estimated decomposing human remains to reach the bloating stage and float to the water's surface after 100-140°C accumulated degree-days (ADD), and a hypothetical estimate of 130°C for a body to generally begin to float. As water temperatures decrease the number of days until a body will begin to bloat and resurface will increase (Tomita 1975). With water reaching nearly freezing temperatures a submerged human body may take several months to resurface (Rodriquez 1997). Figure 2.3 exhibits facial bloat as a result of water submergence for 92.22°C ADD. This individual was recovered in 23.05°C water after being submerged for four days.
Also dependent on temperature is the formation of adipocere. Adipocere, also known as grave wax, is a fatty acid compound that is often found to occur from tissues submerged in water for periods of time (Clark et al. 1997; O'Brien 1997; O'Brien and Kuehner 2007). The conversion of fats into fatty acids requires a water source either from the environment or the deceased's body. Studies by O'Brien (1994, 1997), O'Brien and Kuehner (2007) and Forbes et al. (2011) have found that adipocere formation usually occurs in bodies submerged in warmer water temperatures. However, formation of adipocere has been reported to form in cooler water temperatures as well (Forbes et al. 2011). While adipocere formation requires water to form, if the body remains fully submerged, adipocere may not have a chance to solidify. Most commonly, adipocere is detected on bodies that have resurfaced or washed upon a shore, allowing desiccation and hardening of the adipose tissue (O'Brien 1994; O'Brien and Kuehner 2007).

**Effects of Water Submersion on a Human Body and Methods Used to Estimate PMSI**

After human remains have been recovered from a body of water several postmortem changes are assessed to aid in an estimate of PMI or PMSI. As stated above, decomposition of a body submerged in water is temperature dependent and occurs in a sequential manner. Before the formulation of point-based decomposition scoring systems to predict PMIs, decomposition was visually assessed and divided into sequential stages.
An early study conducted by Payne and King (1972) used pigs as human analogues to assess the decomposition of soft tissue in aqueous environments. They used a six stage sequential system based on stages of submerged fresh, early floating, floating decay, bloated deterioration, floating remains, and sunken remains. In 1993 Haglund used a four point scoring system. He assessed decomposition across 11 areas on bodies from aqueous environments. The main focus of these particular evaluations of anatomical areas was adipocere formation and amount of tissue loss exposing bone. However, Haglund (1993) explained that there are various factors that can affect the decomposition rate of human remains in aqueous environments. Utilizing case reports, autopsy reports, and scene photos from rivers in the United Kingdom, Heaton et al. (2010) revised the Megyesi et al. (2005) point-based terrestrial decomposition scoring system employing ADD to estimate postmortem submersion intervals (PMSI).

A physical trait found in many bodies recovered from water is the presence of “washerwoman skin” (Prahlow 2010). Now an outdated term, washerwoman skin describes the wrinkled physical appearance usually on the hands and feet of bodies submerged in water (Figure 2.4). Heaton et al. (2010) described this physical change as an earlier stage of aquatic submersion. However, succeeding this physical wrinkled appearance the skin will begin to become soggy and eventually slough off in more advanced stages of submerged decomposition (Heaton et al. 2010). Heaton et al. (2010) explained that skin can
Figure 2.4. Wrinkled appearance of hand due to water submersion. La Crosse County Medical Examiner's Office, Chief Medical Examiner: Tim Candahl.
slough off on all areas of the body, but frequently occurs on the hands and the feet and is referred to as “degloving”.

Megyesi et al. (2005) shows a progression of color change from pink/white coloration becoming gray/green over time, eventually resulting in flesh of a brown/black color. However, Heaton et al. (2010) revised this color changing sequence to fit an aquatic environment. While soft tissue modifications of decomposition are similar in terrestrial and aquatic decomposition, these traits often occur at different rates and have different visual markers (Heaton et al. 2010). Instead of skin drying out and possibly reaching the mummified advanced state of decomposition, submerged skin retains water and often displays different colors than those observed in terrestrial decomposition. Heaton et al. (2010) displayed in their aquatic decomposition point-based scoring system a progression from pink, red, green, to black discoloration of the face before eventually sloughing off, and pink, yellow, green, dark green, purple, to black discoloration of the trunk (Figure 2.5). During this progression of color change the bloating of the trunk is increasing and relenting, until the internal organs are soft or liquefied (Heaton et al. 2010).

Following a dark color change of the skin and possible mummification in terrestrial environments Megyesi et al. (2005) listed the last category of decomposition as skeletonization. During this stage the bones become predominantly exposed and dry. Heaton et al. (2010) revised these stages as skeletonization in situ with bone disarticulation and adipose formation. Due to
Figure 2.5. Appearance of color change, red, green and brown, due to water submergence. La Crosse County Medical Examiner's Office, Chief Medical Examiner: Tim Candahl.
several factors of an aqueous environment, after skin sloughing has occurred the bones that are exposed tend to disarticulate (Haglund 1993). In an aqueous environment bodies are often suspended in water allowing movement of the body in three dimensions. This continuous movement, influenced by the water current, aids in soft tissue connection decomposition especially in the joints (Haglund 1993). Heaton et al. (2010) designated the final stages of decomposition to include a progression of skin loss, bone exposure, and disarticulation of the bones.

Megyesi et al. (2005) explained that decomposition occurs differently in three main areas of the body: the head and neck, the trunk, and the limbs. The Heaton et al. (2010) specialized aquatic decomposition scoring method also divided the body into the same three anatomical areas. Therefore, a total body decomposition assessment must be comprised of the individual scores summed together from each of the three anatomical areas. Each of the three anatomical regions has scores ranging from fresh to dry, or in the case of submersion decomposition, fresh to complete disarticulation and skeletonization. A minimum total body score (TBS) of three and a maximum TBS of 35 can be assigned using Megyesi et al. (2005). A minimum total aquatic decomposition score (TADS) of three could be assigned, and a maximum TADS of 25 can be assigned to an individual case. Appendix I provides the descriptive stages of scoring decomposition for each of the three anatomical regions derived from Megyesi et
al. (2005), and Appendix II outlines the descriptive stages of scoring total aquatic decomposition derived from Heaton et al. (2010).

Utilizing ADD and point based scoring systems for decomposition unknown PMIs and PMSIs can be predicted. TADS and TBS create an estimation of ADD allowing for a time since death interval to be approximated with known daily temperatures.

**Concerns Forensic Investigators Face When Determining PMSIs**

While scoring decomposition to predict PMIs and PMSIs can provide an estimate, an exact time since death can never be calculated. As mentioned above, several environmental and body factors can accelerate or impede the rate of decomposition. De Donno et al. (2014) utilized 68 submerged forensic cases to estimate PMSIs in sequestered versus non-sequestered aquatic environments. Utilizing the Heaton et al. (2010) point based decomposition scoring system and ADD they found each forensic case is too unique to predict a PMI (De Donno et al. 2014). While these scoring methods do provide an estimate of PMI and PMSI, a developed method to include all variables affecting decomposition does not exist. An algorithm including all factors of human decomposition in water would have to include clothing, water depth, water obstacles, water temperature, current, water pH levels, marine life activity, state of submersion of floatation, body weight, body mass index, and many more factors (De Donno et al. 2014; Haglund 1993; Payne-James et al. 2011).
Since it is nearly impossible to recreate all of the environmental and body conditions in a controlled setting, forensic cases have been used to study aquatic decomposition (De Donno et al. 2014; Forbes et al. 2011; Heaton et al. 2010; Humphreys et al. 2013; Mateus and Vieira 2014; Megyesi et al. 2005). When utilizing forensic cases many of the mentioned variables are unknown or undocumented. Haglund (1993) expresses that often the point of entry of a submerged body is not known. Bodies can become stuck or snagged below the surface or above the surface in a stationary position. Both of these variables hinder the ability to estimate the water current’s effect on decomposition. Similarly, levels of water pH are not measured, but are found to affect decomposition (Alley 2007; Ayers 2010).

It should also be understood that point based decomposition scoring methods are not suited well for very short PMIs. Both Megyesi et al. (2005) and Heaton et al. (2010) do not take into account physical expressions of algor mortis, livor mortis, or rigor mortis. They also do not consider the hindering affect clothing has on decomposition, or the accelerated affect and pattern of decomposition antemortem or perimortem trauma possibly has on the body (Mann et al. 1990; Smith 2009).

Another very significant problem when using point based decomposition scoring systems to predict ADD and PMI is the lack and accuracy of temperature recordings. Temperatures are rarely recorded in medical examiner/coroner or autopsy reports. Temperatures of many waterways are not recorded daily, if at
all. Water temperatures that are recorded are often recorded at the surface and not at the bottom of the body of water where the temperature is often cooler (Rodriquez 1997). It should also be noted that in colder regions temperature sensors often freeze and are not able to provide an accurate temperature reading (Maddock, Pers. Comm.). Heaton et al. (2010) collected temperature data from environmental agencies, however temperatures of the studied bodies of water were only collected one to three times each month. Using monthly temperature data instead of daily temperature measurements may ensure general instead of accurate estimates of daily temperatures and ADD. However, it may be more beneficial for longer PMSIs to be recorded using daily temperatures, and for temperatures to be recorded by the researcher instead of relying on outside research parties (Heaton et al. 2010).

It should be noted that PMSIs do not always equate to PMIs. Particularly in homicide cases, it is possible that the victim may have been deceased prior to being submerged in water. When using the Heaton et al. (2010) point based decomposition scoring method for aqueous environments ADD are not necessarily predicting time since death, rather time since water submersion.

Utilizing both Megyesi et al. (2005) and Heaton et al. (2010) this research attempts to highlight how water affects the many different expressions of human decomposition. Due to the plethora of environmental and body factors affecting decomposition this study also aims to explore how water submersion impacts PMSI estimates in waterlogged bodies. Additional research of PMSI estimates is
crucial to the study and application of death investigation. More accurate methods of PMSIs and the factors that can affect those estimates are deemed useful to forensic scientists and law enforcement when solving homicide, accidental, and suicide deaths and can aid in the process of human identification (Papadodima et al. 2010; Prahlow 2010).
CHAPTER 3

METHODS

This study is comprised of accidental and suicidal drowning cases obtained from medical examiner and coroner’s offices in Wisconsin and Minnesota. Cases were required to have a known or precisely estimated PMSI and available daily water temperatures. A total of 73 cases from three primary counties, Hennepin County in Minnesota, La Crosse County in Wisconsin, and Manitowoc County in Wisconsin, containing major rivers or lakes were examined (see Figure 3.1). These three counties were chosen for this study because of the frequent amount of water deaths as well as the variability of water temperatures throughout the seasons.

The Mississippi River and Lake Michigan were the main bodies of water examined in this study. The Mississippi headwaters, near Hennepin and La Crosse counties, can often drop to below freezing temperatures in the winter months (US Army Corps of Engineers 2017). An average current flowing south at 1.3 miles per hour keeps the water from freezing. Lake Michigan, bordering Manitowoc County, is the third largest Great Lake at approximately 22,300 square miles. While the entire lake does not entirely freeze over in the winter months, ice typically covers over half of the lake. The lake is 925 feet at its deepest point allowing reservoirs of heat within the lake. According to the Great Lakes Environmental Research Lab, strong winds and contrasting wave actions
Figure 3.1. Hennepin, La Crosse and Manitowoc Counties.
inhibit the lake from entirely freezing over. During the summer months, water
temperatures are recorded between 60 and 70 degrees Fahrenheit (NOAA
2015). These waterways were chosen for this study due to the compatibility in
water temperature fluctuation throughout the seasons as well as the inability for
the body of water to entirely freeze during the winter months.

Permission to access autopsy reports, medical examiner reports, police
reports, and photographs was granted by Dr. Andrew Baker, Hennepin County
Chief Medical Examiner. Hennepin County in Minnesota is bisected by the
Mississippi River. A total of 42 of 102 drowning cases between 2004 and 2014 fit
this study. Permission to access these same materials at the La Crosse County
Medical Examiner’s office in Wisconsin was granted by Timothy Candahl, Chief
Medical Examiner. This county is also bordered by the Mississippi River,
resulting in a total of 20 cases between 1997 and 2017 that fit this study. Chief
Coroner, Curtis Green, of the Manitowoc County Coroner’s Office in Wisconsin
also granted access to reports, resulting in a total of 11 cases from the
Manitowoc River, leading into Lake Michigan, and Lake Michigan from 1998 to
2015 that fit this study. Table 3.1 includes the demographic data of the cases
from each county that fit this study.

While reviewing the case files, three data sets (observations of
decomposition as well as biological profile information, and site/scene
descriptions) were collected for each case utilizing scene reports, autopsy
reports, and photographs. Biological profile observations are defined in
Table 3.1. Demographic data of sampled forensic cases.

<table>
<thead>
<tr>
<th>Area</th>
<th>Males (N)</th>
<th>Females (N)</th>
<th>Totals (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age Range (years)</td>
<td>White</td>
<td>Black</td>
</tr>
<tr>
<td>Hennepin County</td>
<td>14-67</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>La Crosse County</td>
<td>6-72</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Manitowoc County</td>
<td>1-71</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>39</td>
<td>11</td>
</tr>
</tbody>
</table>
Table 3.2. Site/scene descriptions as reported in the death investigation reports are listed in Table 3.3. Observations of the expression of decomposition that were recorded are listed in Table 3.4.

*Accumulated Degree Days*

Until recent years, medical examiner and coroner reports were often not as detailed as a researcher or investigator would anticipate. Cases that were poorly documented dating from the 1990's and early 2000's, were excluded from this study due to lack of photographs, detailed descriptions, and water temperature information. Very few cases had documented water and ambient temperatures recorded. The US Army Corps of Engineers website was utilized to obtain water temperature data for those cases that were undocumented by death investigators. The US Army Corps of Engineers controls each lock and dam on the Mississippi River, and they record a mean daily water temperature. Access to information to the nearest lock and dam system for each individual case was granted to obtain daily water temperatures. Water temperature data from Lock and Dam #1 on the Mississippi River was utilized for all cases in Hennepin County. Lock and Dam #1 PMSI ADD ranged from 0.01°C to 1826.5°C. Water temperature data from Lock and Dam #7 on the Mississippi River was utilized for all cases in La Crosse County. Lock and Dam #7 PMSI ADD ranged from 0.01°C to 917.78°C. Only cases from Manitowoc County with documented daily water temperatures in the site/scene, police, or medical examiner’s report were used in
<table>
<thead>
<tr>
<th><strong>Variable</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>The decedent’s sex as reported by a pathologist, medical examiner, or coroner. Sex was determined using soft tissue characteristics or anthropological techniques when skeletal remains are present.</td>
</tr>
<tr>
<td>Age</td>
<td>Biological age of the individual was determined by the medical examiner or coroner using medical records after the decedent had been positively identified.</td>
</tr>
<tr>
<td>Ancestry</td>
<td>Ancestry of the victim was collected by the death investigator or law enforcement officer who made the positive identification of the victim or by the pathologist at autopsy to describe human variation among populations (Livingstone 1962).</td>
</tr>
<tr>
<td>Weight</td>
<td>The decedent’s weight was recorded from an identification card. Weight is an estimate since these documents contain self-reported weight. Pathologists also document weight of the remains at the time of an autopsy. However since decomposition has taken place and the body has retained water these weights would not reflect the decedent’s antemortem weight.</td>
</tr>
<tr>
<td>Stature</td>
<td>Length of the decedent is an estimate due to the self-reported nature of height obtained from positive identification documents often used, such as a driver’s license (Willey and Falsetti 1991).</td>
</tr>
<tr>
<td>Clothing</td>
<td>Clothing was recorded as absent, lightly clothed if the decedent had a shirt and pants or shorts, and fully clothed if the decedent was dressed in anything more than a shirt and shorts or pants.</td>
</tr>
</tbody>
</table>
Table 3.3. Site and Scene Descriptions as Reported by Coroner/Medical Examiner.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMSI</td>
<td>The known postmortem submersion interval was defined in this study as the reported time of death made by witnesses at the scene or suicide notes until the time the body was recovered. When exact time of death was unknown the date the decedent was last known to be alive is reported as the time of death. Victims submerged for less than 12 hours were excluded from this study. Victims submerged for 12 hours or more were documented by number of days submerged.</td>
</tr>
<tr>
<td>Water Temperature</td>
<td>Water temperature was recorded as average daily temperature of the water in which the decedent was found. It was collected by outside parties such as the US Army Corps of Engineers and the National Oceanic Atmospheric Administration.</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>Ambient temperature was recorded as average daily temperature at the location in which the decedent was found as reported by the National Weather Service.</td>
</tr>
<tr>
<td>Water Depth</td>
<td>The death investigator or law enforcement officer at the scene recorded the depth of the water in which the decedent was found. It was categorized into groups including: no depth if the remains had washed to the shore, shallow if the remains were in less than five feet of water, and deep if the remains were recovered in more than five feet of water (limited visibility).</td>
</tr>
<tr>
<td>Site Description</td>
<td>This is the description of the scene the victim was recovered, often in a river or lake.</td>
</tr>
</tbody>
</table>
Table 3.4. Expressions of decomposition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submerged or Floating remains</td>
<td>If the remains were fully submerged at the scene the decedent was considered sunk, and if the remains were exposed to the water’s surface or washed to a shoreline the body was considered to have been floating.</td>
</tr>
<tr>
<td>Stage of Decomposition</td>
<td>This was reported by pathologists in autopsy reports as no signs of decomposition, early signs of decomposition, moderate decomposition, or advanced decomposition.</td>
</tr>
<tr>
<td>Adipocere</td>
<td>This is the wax like result from anaerobic hydrolysis of fats into fatty acids (Clark et al. 1997; O’Brien 1994).</td>
</tr>
<tr>
<td>Rigor Mortis</td>
<td>This is defined as muscle stiffening due to autolysis of muscle cells, causing the muscle fibers to biochemically bind together (Marks et al. 2009).</td>
</tr>
<tr>
<td>Livor Mortis</td>
<td>This is defined as blood pooling due to lack of circulation throughout the deceased’s body (Clark et al. 1997: Marks et al. 2009).</td>
</tr>
<tr>
<td>Algor Mortis</td>
<td>This is defined as the cooling or warming of the body to reach an ambient temperature (Clark et al. 1997).</td>
</tr>
<tr>
<td>Autolytic Changes to Organs</td>
<td>This was reported by the pathologist performing the autopsy as either absent, beginning; if the organs were soft and decomposition fluid was present, liquefied; if the organs were present but mainly liquid, and reported as complete; if the organ structures were unidentifiable.</td>
</tr>
<tr>
<td>Entomology</td>
<td>This was recorded as presence or absence of either insects or insect bites on the remains as reported by the pathologist at autopsy.</td>
</tr>
<tr>
<td>Anthropophagy</td>
<td>This is the presence of vertebrate animal activity, scavenging, on the body.</td>
</tr>
<tr>
<td>Washerwoman Skin</td>
<td>This is described as the wrinkled physical appearance usually on the hands and feet of bodies submerged in water (Heaton et al. 2010).</td>
</tr>
<tr>
<td>Discoloration</td>
<td>This is the change of color appearance of the body, usually progressing from a green color to a dark brown color as a result of autolytic cell activity (Clark et al. 1997).</td>
</tr>
<tr>
<td>Marbling</td>
<td>This is the result of autolysis of the red blood cells, creating a blue hue of deoxyhemoglobin in the superficial blood vessels (Clark et al. 1997; Prahlow 2010).</td>
</tr>
</tbody>
</table>
### Table 3.4. Continued

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair Slippage</td>
<td>This is the same process as skin slippage, but occurring where there is a presence of copious amounts of hair, such as the head (Clark et al. 1997).</td>
</tr>
<tr>
<td>Skin Slippage</td>
<td>This is defined as the break down of the cellular junctions between the epidermis and dermis, resulting in the epidermis separating from the dermis (Clark et al. 1997).</td>
</tr>
<tr>
<td>Bullae</td>
<td>This is the collection of fluid filled pockets between the dermis and epidermis resulting from autolytic changes of the cellular junctions between the layers of the epidermis and dermis (Clark et al. 1997).</td>
</tr>
<tr>
<td>Bloating</td>
<td>This is the result of autolytic and putrefactive decomposition changes, creating a build up of gas in the soft tissues (Clark et al. 1997).</td>
</tr>
<tr>
<td>Purge</td>
<td>This is the result of the relaxation of the muscles and gas buildup in the gastrointestinal tract leading to expulsion of the gastric contents through the mouth and/or nose (Clark et al. 1997).</td>
</tr>
<tr>
<td>Trauma</td>
<td>Presence of any antemortem, perimortem, or postmortem lesions, bruises, breaks, or bone fractures as reported by the pathologist, medical examiner, or coroner.</td>
</tr>
</tbody>
</table>
this study due to the lack of reliable temperature gauges in the Manitowoc River and the shores of Lake Michigan (K. Schrader, Pers. Comm 2016). These PMSI ADD ranged from 0.01°C to 191.67°C. Water temperatures of 32°F or below were assigned as 0.01°C to avoid negative ADD. The total range of ADD for all decedents in this study is from 0.01°C to 1826.5°C with a mean ADD of 140.63°C.

**Measuring Decomposition**

Each case was evaluated and scored utilizing scene reports, autopsy reports and photographs. Detailed notes were taken, and the data were scored at a later date. Decomposition scores can be found in Appendix III. Not all cases had similar available sources to collect data from. Some cases did not have available photographs, while others did not include autopsy reports. Therefore, scoring at a later date utilizing detailed notes eliminated some biases.

In order to assess decomposition, this study utilized methods from the Megyesi et al. (2005) point-based scoring system as well as the Heaton et al. (2010) point-based scoring system. The Heaton et al. (2010) scoring system is a revised version of Megyesi et al. (2005) created specifically to score aquatic/submersion decomposition. By using point-based scoring systems in conjunction with accumulated degree-days (ADD), an estimated PMSI can be determined and compared to the known PMSI. Heaton et al. (2010) explained that similar types of soft tissue modifications occur in similar sequences and
therefore are not dependent on the type of aquatic site. It is suggested that the sequence of decomposition is comparable between all types of waterways, allowing the same methods of visual assessment of postmortem modification to be utilized for each case in this study.

In order to assess how the land based decomposition scoring method (Megyesi et al. 2005) and the water based scoring method (Heaton et al. 2010) compared to one another and to determine which method was more accurate this study had three components. First, after scoring bodies from photographs and assigning a TBS/TADs score, ADD were calculated and compared for each method to understand if both scoring methods predict equivalent or interchangeable estimates. Second, PMSIs were calculated from TBS and TADS scores, and then were compared to one another to determine which method is more accurate and which method was more appropriate for waterlogged bodies. The third component of this study compared how these methods work for cases in three different temperature categories.

To calculate ADD estimation using methods derived from Megyesi et al. (2005) the following formula is required:

\[
ADD = 10^{(0.002 \times TBS \times TBS + 1.81)} \pm 388.16
\]

A standard regression error is included as ±388.16. To calculate ADD estimation using TADS Heaton et al. (2010) utilized the equation:

\[
TADS = -3.706 + 7.778 \times \log ADD
\]

or
(ADD=10^{(TADS+3.706)/7.778})

With an assigned TBS or TADS, an estimation of PMSI can be made using known ADD from the time of body discovery to the time of known submersion. Microsoft Excel (Katz 2010) was utilized to calculate all TBS and TADS scores.

To test for an intraobserver error, I re-scored 25% or 19 of the cases for TBS and TADS. The estimated ADD was then compared to the initial score’s estimated ADD using a paired t-test for both decomposition-scoring methods using the statistical program, R studio 1.0.136 (2013).

After estimated ADD were calculated using both TBS and TADS, each method was compared to the actual ADD retrieved from autopsy, coroner, medical examiner, or police reports. A regression analysis was utilized to test TBS against the actual and the predicted log_{10} ADD, as well as TADS against the actual and predicted log_{10} ADD to understand the relationship between the variables. A p-value < .05 was considered significant. Regression analyses predict the type of relationship between independent (TBS or TADS) and dependent (calculated/predicted ADD) variables. Simmons et al. (2010) and De Donno et al. (2014) explain that decompositional scoring systems matched against log_{10} ADD allows for the expression of a simple linear equation to represent decomposition’s exponential progression. ADD temperatures were subjected to the log_{10} function to normally distribute the data and for the temperatures to appear more logically when charted. A Pearson’s product moment correlation was used to compare the estimated and actual calculated
ADD based on water temperatures. Using a Pearson’s product moment correlation allowed for the strength of a linear association between two variables to be measured. An absolute value of the r-value 0.1 to .3 was considered as a low correlation, from 0.3 to 0.5 as a medium correlation, and 0.5 to 1.0 as a high correlation. Actual ADD and estimated ADD from each scoring method were then compared, as well as the predictive methods with each other, using a repeated-measures ANOVA test using SPSS to examine if the sample means were significantly different (IBM Corp., 2016).

The estimated PMSI was then compared to the actual PMSI using a paired t-test for both decomposition-scoring methods using the statistical program, R studio 1.0.136 (2013). Thirteen cases were excluded from this assessment due to the large number of days that were documented as 0°C. The estimated PMSI for the Megyesi et al. (2005) and the Heaton et al. (2010) were then compared to one another using a paired t-test. Comparing estimated PMSIs to actual PMSIs from two different scoring methods, Megyesi et al. (2005) and Heaton et al. (2010), will attempt to answer how water submersion impacts PMSI estimates in waterlogged bodies. Specifically, the results from each scoring method will attempt to answer the first research question regarding how water submersion affects the decomposition process and rate of decomposition.

Cases were also categorized and statistically analyzed in R (2013) using the same regression analysis and Pearson’s product moment correlation analysis methods as above according to temperature categories. Using actual ADD
calculated from water temperatures and a chosen temperature threshold, cases were split between three groups according to ADD: ADD 25°C and under, ADD between 26°C and 100°C, and ADD over 100°C. A two-tailed t-test was also utilized to determine if each predicted decomposition scoring method was significantly different from the actual calculated water temperatures. A p-value of less than 0.05 was considered significantly different. These analyses determine which decomposition scoring method best predicts PMSI for different water temperatures.
CHAPTER 4

RESULTS

General Observations

The degree of decomposition varied within the cases studied. Known PMSIs ranged from one day to 258 days. Observations from fresh/no physical changes to limb disarticulation and bone exposures were recorded. All 73 cases retained most of the soft tissues. One case showed partial decapitation due to extensive decomposition. Ten cases were recorded as having exposure of the organs, and four cases showed bone exposure in the hands or limbs. All but 12 cases were considered fully clothed. Twenty cases showed entomological evidence or anthropophagy. Antemortem or perimortem trauma was found in 24 cases, with 17 of the cases classified as having open flesh wounds.

Statistical Analysis

The data used in this study fit both the Megyesi et al. (2005) and the Heaton et al. (2010) body scoring methods well. A regression analysis for TBS against predicted log_{10}ADD based on the Megyesi et al. (2005) model was explored ($r^2=0.9369$, $F_{1.71}=1071$, $p<2.2e^{-16}$). The $r^2$ value is the variation in Y explained by the variation in X. A $r^2$ value greater than 0.25 indicates a significant relationship between the X and Y. A better fit is considered the closer the $r^2$ value is to one. The F value is the probability that the null hypothesis is true. The value of F
ranges between zero and an arbitrarily large number. The p-value indicates whether or not the null hypothesis can be rejected. A low p-value of <0.05 will reject the null hypothesis, while an insignificant p-value of >0.05 will indicate that the changes in the predictor are not associated with the changes in the response.

Data were then subjected to a regression analysis between TBS and ADD calculated from the water temperatures to estimate the relationship between the two variables. The regression model for TBS against log_{10}ADD based on water temperatures (Fig. 4.1) fits the data well and is considered significant ($r^2=0.3486$, $F_{1,71}=37.99$, $p<0.0001$). The data were tested for an intraobserver error for each decomposition scoring method using a t-test, and no significant differences were found (Megyesi et al. (2005): $t=1.4377$, df=21, $p=0.1677$; Heaton et al. (2010): $t=1.7143$, df=18, $p=0.1036$). The t-value indicates difference size between the two sets of data. The t-value can be positive or negative, and the further the value is from zero indicates there is not a significant difference between the two data sets. The df-value is the degrees of freedom, and the p-value less than 0.05 rejects the null hypothesis, while a p-value of greater than 0.05 accepts the null hypothesis.

A regression analysis for TADS against log_{10}ADD based on the Heaton et al. (2010) regression model was explored ($r^2=0.9994$, $F_{1,71}=1.289e^5$, $p<0.0001$). The regression model for TADS against log_{10}ADD based on actual water temperatures (Fig. 4.2) also fits the data well, and the relationship between the two variables is considered significant ($r^2=0.3413$, $F_{1,71}=36.78$, $p<.0001$).
Figure 4.1. Total body score against log$_{10}$ calculated actual accumulated degree-days ($r^2=0.3486$, $F_{1,71}=37.99$, $p<0.0001$). Gray areas indicated confidence intervals.
Figure 4.2. Regression of total Aquatic Decomposition Score against log_{10} calculated actual accumulated degree-days ($r^2=0.3413$, $F_{1,71}=36.78$, $p<.0001$). Gray areas indicated confidence intervals.
Actual ADD calculated from water temperatures was then compared to the predicted ADD for both Megyesi et al. (2005) and Heaton et al. (2010) methods using Pearson’s product moment correlations to understand the linear relationship between the two sets of temperatures. Figure 4.3 indicates a positive linear correlation between the Megyesi et al. (2005) predicted ADD and the actual ADD ($r=0.5756781$). A r-value can range from -1 to 1 depending on the type of association (negative or positive) between the two variables. The closer the r-value is to zero indicates a weaker association and vice-versa. As an r-value approaches zero, the plot will appear more scattered and further from the line of best fit. A positive linear correlation was also found between the Heaton et al. (2010) predicted ADD and the actual calculated ADD ($r=0.5922739$) (Fig. 4.4). A strong correlation ($r=0.8860195$) was found between both Megyesi et al. (2005) and Heaton et al. (2010) predicted ADD methods (Fig. 4.5).

A repeated-measures ANOVA was used to compare the means of each ADD predictive method and the actual calculated ADD from water temperatures. The results show there is no significant difference between the three data sets (Table 4.1). An F statistic is the ratio of the variation within the subject to the error variation and measures how far the data are from the mean. Larger F scores indicate greater dispersion from the mean. A p-value greater than 0.05 indicates that the means are not significantly different. While there was no significant difference between the Megyesi et al. (2005) predicted ADD and the actual ADD calculated from water temperatures, the Megyesi et al. (2005) method over
Figure 4.3. Pearson's product moment correlation between log$_{10}$ actual calculated ADD and log$_{10}$ Megyesi et al. (2005) predicted ADD ($r=0.5756781$).
Figure 4.4. Pearson’s product moment correlation between $\log_{10}$ actual calculated ADD and $\log_{10}$ Heaton et al. (2010) predicted ADD ($r=0.5922739$).
Figure 4.5. Pearson’s product moment correlation between $\log_{10}$ Heaton et al. (2010) predicted ADD and $\log_{10}$ Megy esi et al. (2005) predicted ADD ($r=0.8860195$).
Table 4.1. Repeated-Measures ANOVA comparing differences in means between the Megyesi et al. (2005) predicted ADD Celsius, the Heaton et al. (2010) predicted ADD Celsius, and the calculated ADD from water temperatures Celsius.

<table>
<thead>
<tr>
<th>(I) factor1</th>
<th>(J) factor1</th>
<th>Mean Difference</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>95% Confidence Interval for Difference&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (Megyesi ADD)</td>
<td>2</td>
<td>10.397</td>
<td>25.386</td>
<td>.683</td>
<td>-40.210</td>
<td>61.003</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>23.286</td>
<td>23.498</td>
<td>.325</td>
<td>-23.557</td>
<td>70.129</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. (Heaton ADD)</td>
<td>1</td>
<td>-10.397</td>
<td>25.386</td>
<td>.683</td>
<td>-61.003</td>
<td>40.210</td>
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<tr>
<td>3</td>
<td>12.889</td>
<td>11.138</td>
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<tr>
<td>3. (ADD)</td>
<td>1</td>
<td>-23.286</td>
<td>23.498</td>
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<td>-70.129</td>
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Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).
predicted ADD (F=23.286, p=0.325). The Heaton et al. (2010) method also tended to over predict ADD (F=12.889, p=0.251). Of the two predictive ADD methods the Megyesi et al. (2005) method over predicted ADD twice as much in comparison to the Heaton et al. (2010) method (F=10.397, p=.683).

A paired t-test was used to compare the estimated PMSI to the actual PMSI for both decomposition-scoring methods for 60 cases. The results indicate no significant difference between the actual PMSI and the estimated PMSI using the Megyesi et al. (2005) method (t=-15784, df=59, p=0.1198). No significant difference was found between the actual PMSI and the estimated PMSI using the Heaton et al. (2010) method (t=0.010479, df=59, p-value=0.9917). The estimated PMSI for the Megyesi et al. (2005) and the Heaton et al. (2010) were then compared to one another using a paired t-test. The results indicate no significant difference between the two estimated PMSIs (t=1.9166, df=59, p-value=0.06014).

Data were then split into three subgroups according to actual calculated water temperatures. Group A consisted of 29 cases with ADD of 25.8°C or below. The data were subjected to a regression analysis, which indicated a non-significant relationship between the two variables when using the Megyesi et al. (2005) model ($r^2=0.03442, F_{1,27}=0.9625, p: 0.3353$) (Fig. 4.6) as well as the Heaton et al. (2010) model ($r^2=0.06273, F_{1,27}=1.807, p: 0.19$) (Fig. 4.7). Group A was then analyzed using Pearson’s product moment correlation (Fig. 4.8 and Fig. 4.9) for each body scoring method. The results show a low negative correlation.
Figure 4.6. Regression of total body score against log10 calculated actual accumulated degree-days ($r^2=0.03442$, $F_{1,27}=0.9625$, $p: 0.3353$). Gray areas indicated confidence intervals.
Figure 4.7. Regression of total aquatic decomposition score against log_{10} calculated actual accumulated degree-days ($r^2=0.06273$, $F_{1,27}=1.807$, $p: 0.19$). Gray areas indicated confidence intervals.
Figure 4.8. Pearson’s product moment correlation between $\log_{10}$ Megyesi et al. (2005) predicted ADD and $\log_{10}$ calculated actual ADD ($r=-0.1559689$).
Figure 4.9. Pearson’s product moment correlation between log$_{10}$ Heaton et al. (2010) predicted ADD and log$_{10}$ calculated actual ADD ($r=-0.219079$).
as found between TBS and actual calculated water temperatures for the Megyesi et al. (2005) scoring method ($r=0.1559689$) as well as the Heaton et al. (2010) scoring method ($r=0.219079$). The actual calculated ADD was then subjected to a two-tailed t-test compared to the Megyesi et al. (2005) scoring method ($p<0.001$) and another comparing to the Heaton et al. (2010) method ($p<0.001$).

Each method was found to have significantly different predicted mean ADD in comparison to calculated ADD from water temperatures.

Group B consisted of 22 cases with ADD between 26°C and 99°C. This data set was also subjected to a regression analysis, which indicated a significant relationship between the two variables when using the Megyesi et al. (2005) model ($r^2=0.3769, F_{1,20}=12.1, p<0.005$) (Fig. 4.10) as well as the Heaton et al. (2010) model ($r^2=0.5845, F_{1,20}=28.13, p<0.0001$) (Fig. 4.11). Group B was then analyzed using Pearson’s product moment correlation (Fig. 4.12 and Fig. 4.13) for each body scoring method. The results show a high positive correlation found between TBS and actual calculated water temperatures for the Megyesi et al. (2005) scoring method ($r=0.55$) as well as the Heaton et al. (2010) scoring method ($r=0.765$). The actual calculated ADD was then subjected to a two-tailed t-test compared to the Megyesi et al. (2005) scoring method and the Heaton et al. (2010) method. The Megyesi et al. (2005) scoring method mean ADD was significantly different than the actual water temperature mean ($p<0.0001$), while the Heaton et al. (2010) scoring ADD mean was not significantly different form the actual water temperature mean ($p>0.05$).
Figure 4.10. Regression of total body score against log$_{10}$ calculated actual accumulated degree-days ($r^2=0.3769$, $F_{1,20}=12.1$, $p<0.005$). Gray areas indicated confidence intervals.
Figure 4.11. Regression of total aquatic decomposition score against log\textsubscript{10} calculated actual accumulated degree-days ($r^2=0.5845$, $F_{1,20}=28.13$, $p<0.0001$). Gray areas indicated confidence intervals.
Figure 4.12. Pearson’s product moment correlation between log_{10} Megyesi et al. (2005) predicted ADD and log_{10} calculated actual ADD (r=0.55).
Figure 4.13. Pearson’s product moment correlation between log_{10} Heaton et al. (2010) predicted ADD and log_{10} calculated actual ADD ($r=0.765$).
Group C consisted of 22 cases with ADD of 100°C and over. The data were subjected to a regression analysis, which indicated a significant relationship between the two variables when using the Megyesi et al. (2005) model ($r^2=0.5472$, $F_{1,20}=24.17$, $p<0.0001$) (Fig. 4.14) as well as the Heaton et al. (2010) model ($r^2=0.5743$, $F_{1,20}=26.99$, $p<0.0001$) (Fig. 4.15). Group C was then analyzed using Pearson’s product moment correlation (Fig. 4.16 and Fig. 4.17) for each body scoring method. The results show a high positive correlation as found between TBS and actual calculated water temperatures for the Megyesi et al. (2005) scoring method ($r=0.801$) as well as the Heaton et al. (2010) scoring method ($r=0.758$). The actual calculated ADD was then subjected to a two-tailed t-test compared to the Megyesi et al. (2005) scoring method and the Heaton et al. (2010) method. The Megyesi et al. (2005) scoring method mean ADD was significantly different than the actual water temperature mean ($p<0.05$), while the Heaton et al. (2010) scoring ADD mean was not significantly different from the actual water temperature mean ($p>0.05$).
Figure 4.14. Regression of total body score against log$_{10}$ calculated actual accumulated degree-days ($r^2=0.5472$, $F_{1,20}=24.17$, $p<0.0001$). Gray areas indicated confidence intervals.
Figure 4.15. Regression of total aquatic decomposition score against log_{10} calculated actual accumulated degree-days ($r^2=0.5743$, $F_{1,20}=26.99$, $p<0.0001$). Gray areas indicated confidence intervals.
Figure 4.16. Pearson’s product moment correlation between log$_{10}$ Megyesi et al. (2005) predicted ADD and log$_{10}$ calculated actual ADD ($r=0.801$).
Figure 4.17. Pearson’s product moment correlation between log$_{10}$Heaton et al. (2010) predicted ADD and log$_{10}$ calculated actual ADD ($r=0.758$).
CHAPTER 5

DISCUSSION

Trends in Aqueous Decomposition

The focus of this study was to assess aquatic human decomposition in various water temperatures and to understand how aquatic environments and various temperatures affect our ability to use body scoring methods by Megyesi et al. (2005) and Heaton et al. (2010) to predict PMSI in an aqueous environment. The data fit both the Megyesi et al. (2005) and the Heaton et al. (2010) body scoring methods well. However, when the data were split into three separate water temperature categories the results showed that colder water temperatures as well as short known PMSIs inhibit the ability to accurately predict PMSI using body scoring methods.

I noticed trends of decomposition and factors that inhibited trends in an aquatic environment. The decedents that had the shortest PMSIs had a distinct pallor similar to what is seen in terrestrial environments shortly after death. This is often cited as the first sign of decomposition (Clark et al. 1997). The proceeding indicators of decomposition seen in stationary or terrestrial environments such as rigor mortis, livor mortis, and algor mortis, all fluctuated according to several different variables. Rigor mortis was seen in decedents who had been submerged from 12 hours to 39 days. While many death investigators understand rigor mortis often can relent after 24 hours it is important to take into
account ambient temperature, in this case water temperature, and prior physical activity to death (Amendt et al. 2010; Prahlow 2010). Physical activity prior to death increases the onset of rigor mortis, while lower temperatures can dramatically slow the process of rigor mortis as seen in 12 decedents in this study. Variations in onset of algor mortis and livor mortis were also seen in this study due to variations in water temperatures, water current, and fluctuating body position within the moving water.

Discoloration was seen in all decedents who had PMSI of more than one day in warmer water temperatures. Those submerged in cold or freezing water temperatures and also recovered in cold or freezing water temperatures exhibited red discoloration especially in the face and green discoloration in the abdomen. Marbling was usually only detected in those submerged in warmer temperatures in earlier stages of decomposition. Purple and black discoloration was only seen in those individuals who were recovered from warm water temperatures. Those individuals who were recovered in cold temperatures and had extended PMSIs did not reach the extent of decomposition that produced a purple/black discoloration.

Decedents were recorded whether they were floating or submerged in the water. Heaton et al. (2010) specifies whether the remains are pre-bloat, bloating or post-bloat. Often the remains that are not in a state of bloat will remain submerged in the water until they become bloated enough to cause them to float to the surface (Haglund 1993). It is estimated that decomposing human remains
reach the bloating stage and float to the surface of the water after 100-140°C ADD (Mateus and Vieira 2014). However, 28 cases in this study had not reached 100 ADD and were detected floating at the water’s surface. Decedents recovered in freezing water temperatures with extended PMSIs were often found in floating positions without any evidence of bloat and few signs of decomposition. It is possible that these decedents had died with air in their lungs, causing them to float to the surface, or that the bloat stage had been prolonged due to the cold water temperatures making evidence of bloating very subtle. One other explanation could be that those individuals who were both submerged and recovered from freezing water had frozen appendages or were completely frozen causing buoyancy. Four cases in this study were documented as completely frozen.

While skin wrinkling (washerwoman skin) occurred in almost all submerged individuals, the occurrence and usual sequence of skin slippage, hair slippage, and degloving was not always detected. According to Clark et al. (1997) skin slippage can occur as early as 48 hours postmortem. Megyesi et al. (2005) consider skin slip to be an early stage of decomposition, while Heaton et al. (2010) classify it to occur later in the decomposition process in an aqueous environment. The Heaton et al. (2010) scoring method expects skin slippage to occur at the same time on the face and the abdomen. Shortly after, skin slippage on the hands (degloving) and hair slippage should occur. Skin slippage was detected in this study as early as three days post-submersion in warm water
temperatures, while hair slippage was seen four days post-submersion in warm water temperatures. Both hair and skin slippage was not detected until seven days post-submersion in cold aqueous environments. Fifteen cases with PMSI of more than four days exhibited skin slippage without any signs of hair slippage. One case with a PMSI of 126 days showed signs of skin slippage on the limbs, but none was detected on the abdomen or face, nor were there signs of hair slippage. A single case was recorded as exhibiting hair slippage without signs of skin slippage on the body. Both of these anomalies occurred in water with very low calculated ADD. An explanation for these anomalies is most likely the amount of clothing the decedent was wearing. Clothing protects the remains from various factors, including anthropophagy and debris in the water. Without direct contact to the water the clothing may act as a barrier allowing the integrity of the skin to remain intact for longer periods of submersion. In each of the cases of extended PMSIs all of the decedents were considered to be fully clothed, including the presence of shoes.

Only one case in the study had extensive decomposition that led to skeletonization of the cranium as well as bone exposure in the limbs. This case had a PMSI of 35 days in the summer, and was not wearing any clothing when the body was recovered. The body was recovered in an open river. Three other cases had bone exposure occurring in the limbs or hands. A combination of lack of clothing in these areas, increased ADD, and open river currents constantly
altering the position of the body allowed for an accelerated rate of decomposition to occur in the water.

As the regression model indicates in Figure 4.2 a significant correlation between TBS and calculated water temperature ADD was found using the Megyesi et al. (2005) method. However, it can be noticed that the smallest and largest ADDs have increasing distances between the confidence intervals. This is also true using the Heaton et al. (2010) aquatic body scoring method in Figure 4.4. De Donno et al. (2014) explained that a higher ADD results in a less accurate estimation of ADD. However, because most body scoring methods do not take into account early signs of decomposition, such as rigor mortis and livor mortis, the estimation of short PMSIs will also be less accurate.

Low ADD measures can be due to short PMSIs. However, several cases in this study have been subjected to cooler water temperatures for extended periods of time. This study explored how ADD can affect our estimation of PMSI. When the cases were split into categories according to ADD temperatures it was concluded that those bodies recovered in the coolest temperatures as well as those that were in the water for the shortest amount of time had the least accurate PMSI estimations. Inaccurate estimations can arise from a variety of factors. As previously mentioned, body scoring methods do not take into account early signs of decomposition. Methods assign a score of “1” when no physical changes are found, and a score of “2” when observations such as marbling and skin slippage are seen. However, in aquatic decomposition many postmortem
changes, such as rigor mortis, livor mortis, and shades of discoloration that can be attributed to various water temperatures, occur between the stages assigning scores of 1 and 2 points. Those decedents that were recovered from cooler water temperatures show signs of discoloration as a consequence of freezing instead of decomposition, resulting in the assignment of a higher TBS and TADS score leading to increased ADD estimations.

Two cases with extended PMSIs (64 and 119 days) from group A, 25.8°C or below, had extreme overestimations of ADD as results of both decomposition scoring methods. As in the 64 day PMSI case, the body was submerged in below freezing temperature water. The body was observed to have undergone the process of bloat. However the presence of bloat was a consequence of water retention instead of anaerobic decomposition. This submersion in a water system comprising a strong current caused the body to almost entirely freeze. Constant exposure of the decedent to water still allowed for decomposition observations such as skin slippage, hair slippage and slight discoloration due to the body freezing. Evidence of bloat due to water retention, skin slippage, and hair slippage caused the decomposition observations to fit into advanced stages of decomposition according to scoring methods used, even though the body did not show evidence that it had undergone any earlier stages of decomposition. With increased TBS and TADS scores due to submersion, increased predicted ADDs resulted even though the water was below freezing. Upon internal examination,
no evidence of autolytic decomposition had occurred from a halted anaerobic decomposition as a result of the below freezing water temperatures.

The decedent submerged for 119 days was recovered in above freezing temperatures, but was submerged in below freezing temperatures for almost the entirety of the PMSI. The six days before recovery of the decedent the water temperatures rose, allowing for an accelerated rate of decomposition. Micozzi (1986) explained that the process of freezing causes a halt in anaerobic decomposition, but increases aerobic decomposition when thawed. This increase in aerobic decay, as opposed to putrefaction caused by anaerobic decomposition, allowed for advanced stages of decomposition to be observed. Water retention also caused an appearance of bloat. Consequently larger ADD estimations were assigned, resulting in an overestimation of PMSI.

All of the cold-water submersion in this study resulted in an overestimation of PMSI due to the factors listed above, such as observations of bloat due to water retention instead of decomposition. Increased intervals of submersion leading to water retention of the body played a large role in deterioration of the skin, resulting in decomposition changes such as skin slippage, hair slippage, and degloving. While the Megyesi et al. (2005) and the Heaton et al. (2010) methods consider these to be consequences of anaerobic decomposition (putrefaction) water retention, even in below freezing temperatures, can cause observations of advanced stages of decomposition, resulting in overestimations of ADD.
While prediction of ADD led to inaccurate PMSI estimates of those decedents with short PMSI intervals and those in cold water temperatures, the cases in group B, 26°C to 99°C ADD, were much more predictable. A high positive correlation was found between both scoring methods and ADD calculated from water temperatures. Overall, both scoring methods tended to over predict ADD, however the Heaton et al. (2010) method did not have a significantly different ADD mean when compared to calculated water temperature ADD. The Megyesi et al. (2005) method did produce a significantly different ADD mean when compared to the calculated water temperature ADD. This is most likely due to the inability to score submerged remains in any of the scoring stages that include desiccated or mummified descriptions due to the nature of an aqueous environment.

The results for group C, 100°C ADD and over, were similar to that of group B. The Megyesi et al. (2005) method tended to over predict ADD estimations for this study as a whole, however it under predicted 7 of the 22 cases in this group by 50°C or more. The mean ADD predicted using the Megyesi et al. (2005) method was significantly different than the calculated water temperature ADD for this group due to these under predictions and a few over predictions of ADD. Under prediction of ADD using the Megyesi et al. (2005) method can, again, be explained by the inability to surpass scoring categories involving descriptions of desiccated or mummified remains due to an aqueous environment in place of a terrestrial environment. The Heaton et al. (2010)
scoring method fit this data group well due to the detailed descriptions and scoring stages of advanced decomposition usually observed in cases with larger ADD estimates. The results and observations of decomposition from this study show that the beginning stages of aquatic decomposition do not always occur in a sequential predicted manner. However, stages of decomposition post skin slippage are described as sequential stages of skeletonization and loss of soft tissue integrity. The loss of soft tissue and process of skeletonization can be halted or prolonged due to cooler water temperatures, but these processes cannot be reversed or observed in a nonsequential fashion.

The results indicate that both the Megyesi et al. (2005) and the Heaton et al. (2010) decomposition scoring methods fit the data well. Overall, each method was able to predict PMSIs for the data in this study. However, when the data were split into categories of ADD the results varied. Both decomposition scoring methods proved unfit to predict short PMSIs and cases that were submerged in cold water conditions with low ADD of 25°C and under. Both methods of decomposition scoring showed high positive correlations for PMSI predictions for cases with ADD between 26°C and 99°C. While the Megyesi et al. (2005) method tended to over predict PMSIs in an aqueous environment compared to the Heaton et al. (2010) model, the predicted ADD mean was not significantly different than the actual calculated ADD for group B cases. Group C cases consisting of ADD of 100°C and over had similar results to that of group B, except that the predicted ADD mean was significantly different than the actual
calculated ADD using the Megyesi et al (2005) model. The results indicate the Heaton et al. (2010) model is best fit to estimate PMSIs. However, the Heaton et al. (2010) model does not possess the ability to predict short PMSIs and PMSIs with low ADD as a result of cold or freezing water temperatures.

The incorporation of the Megyesi et al. (2005) method into this study allowed for an understanding of the sequence of human decomposition, and to determine which variables create an alteration in this pattern when attempting to understand and score aquatic decomposition. By utilizing both the Megyesi et al. (2005) scoring method as well as the Heaton et al. (2010) scoring method it was able to be determined that the Heaton et al. (2010) scoring method does not address all the necessary alterations to the Megyesi et al. (2005) method in order to provide an all-encompassing aquatic scoring method. While research conducted by Heaton et al. (2010) to formulate an aquatic scoring method was never compared to or scored using the Megyesi et al. (2005) method, results from this study confirm that aquatic decomposition may not always follow a specific sequence. The Heaton et al. (2010) method is best fit for the specific study sample it was created for. Results indicate that additional alterations to the aquatic scoring method should be considered when attempting to score cases with extremely low or high ADD.
CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to assess aquatic human decomposition in various water temperatures and to understand how aquatic environments and various water temperatures affect our ability to use body scoring methods by Megyesi et al. (2005) and Heaton et al. (2010) to predict PMSI in an aqueous environment. Results highlight broad findings of an abnormal pattern of aqueous human decomposition in cold-water environments as well as the inability to use decomposition scoring methods to predict short PMSIs and PMSIs with low ADD calculations due to low water temperatures.

The results indicate that cold water submersion allows for certain decomposition processes to occur as a result from retaining fluid, instead of anaerobic decomposition. Bloating was noticed in cold-water cases as a result of water retention and not from actual gaseous buildup. Constant exposure to cold water allowed for features of decomposition such as skin slippage, hair slippage, skin wrinkling, and degloving of the hands and/or feet to progress, while other features of decomposition were halted or delayed. An overall trend in aquatic decomposition can therefore not be predicted due to these issues as a result of cooler water temperatures.

Overall, both decomposition scoring methods by Megyesi et al. (2005) and Heaton et al. (2010) were able to predict ADD that were not significantly different
from the actual ADD calculated from water temperatures. While these methods proved to be inaccurate for estimating short PMSIs and PMSIs with low ADD due to cold water temperatures, they were more able to accurately predict PMSIs with cumulative ADDs between 26°C and 99°C.

This study contributes valuable information to the field of anthropology as well as medicolegal death investigation by providing additional research of PMSI estimates to understand the accuracy of each method, as well as the circumstantial nature of their applicability. More accurate methods of PMSIs and the factors that can affect those estimates are deemed useful to forensic scientists and law enforcement when solving homicide, accidental, and suicide deaths and can aid in the process of human identification.

Most importantly, this study demonstrates the need for more accurate decompositional scoring methods. The purpose of the research conducted by Heaton et al. (2010) was to improve on the Megyesi et al. (2005) method and alter the method to fit an aquatic environment. Results indicate that the Heaton et al. (2010) method more accurately predicted PMSIs. However, this study indicates the need for a more accurate method that understands the effects that cold or freezing water submersion has on the decomposition process. The results also indicate a need for more accurate decomposition scoring methods to predict extended PMSIs or PMSIs with ADD over 100°C.

Future directions should continue to explore the effects water temperature has on human the decomposition process. The Heaton et al. (2010) model
serves best to predict PMSIs of individuals submerged in warmer water temperatures. This model could possibly be altered to consider body color alterations due to cold or freezing temperatures and the other non-sequential consequences listed above, such as skin slippage, hair slippage, and bloating due to water retention instead of anaerobic decomposition.
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Prahlow, Joseph

R Core Team

Rodriguez, W C

Rodriguez, WC and WM Bass

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Simmons, T., Adlam, R. E., & Moffatt, C. 

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APPENDIX
Appendix I. Megyesi et al. (2005) Decomposition Scoring Tables

Categories and stages of decomposition for the head and neck (from Megyesi et al. (2005)).

A. Fresh
   (1 pt) 1. Fresh, no discoloration

B. Early decomposition
   (2 pts) 1. Pink-white appearance with skin slippage and some hair loss.
   (3 pts) 2. Gray to green discoloration: some flesh still relatively fresh.
   (4 pts) 3. Discoloration and/or brownish shades particularly at edges, drying of nose, ears, and lips.
   (5 pts) 4. Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present.
   (6 pts) 5. Brown to black discoloration of flesh.

C. Advanced decomposition
   (7 pts) 1. Caving in of the flesh and tissues of eyes and throat.
   (8 pts) 2. Moist decomposition with bone exposure less than one half that of the area being scored.
   (9 pts) 3. Mummification with bone exposure less than one half that of the area being scored.

D. Skeletonization
   (10 pts) 1. Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.
   (11 pts) 2. Bone exposure of more than half the area being scored with desiccated or mummified tissue.
   (12 pts) 3. Bones largely dry, but retaining some grease.
   (13 pts) 4. Dry bone
Categories and stages of decomposition for the trunk (from Megyesi et al. (2005)).

A. Fresh
   (1 pt)  1. Fresh, no discoloration

B. Early decomposition
   (2 pts) 1. Pink-white appearance with skin slippage and marbling present.
   (3 pts) 2. Gray to green discoloration: some flesh still relatively fresh.
   (4 pts) 3. Bloating with green discoloration and purging of decompositional fluids.
   (5 pts) 4. Postbloating following release of the abdominal gases, with discoloration changing from green to black

C. Advanced decompositoin
   (6 pts) 1. Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity.
   (7 pts) 2. Moist decomposition with bone exposure less than one half that of the area being scored.
   (8 pts) 3. Mummification with bone exposure less than one half that of the area being scored.

D. Skeletonization
   (9 pts) 1. Bone with decomposed tissue, sometimes with body fluids and grease still present.
   (10 pts) 2. Bones with desiccated or mummified tissue covering less than one half of the area being scored.
   (11 pts) 3. Bones largely dry, but retaining some grease.
   (12 pts) 4. Dry bone.
Categories and stages of decomposition for the limbs (from Megyesi et al. (2005)).

A. Fresh
   (1 pt)  1. Fresh, no discoloration

B. Early decomposition
   (2 pts)  1. Pink-white appearance with skin slippage of hands and/or feet.
   (3 pts)  2. Gray to green discoloration: marbling: some flesh still relatively fresh.
   (4 pts)  3. Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities.
   (5 pts)  4. Brown to black discoloration, skin having a leathery appearance.

C. Advanced decompositoin
   (6 pts)  1. Moist decomposition with bone exposure less than one half that of the area being scored.
   (7 pts)  2. Mummification with bone exposure less than one half that of the area being scored.

D. Skeletonization
   (8 pts)  1. Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining.
   (9 pts)  2. Bones largely dry, but retaining some grease.
   (10 pts) 3. Dry bone.
### Appendix II. Heaton et al. (2010) Decomposition Scoring Tables

Descriptive stages for decomposition observed in the face and the assigned facial aquatic decompositional score (FADS) (from Heaton et al. (2010)).

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pt</td>
<td>No visible changes.</td>
</tr>
<tr>
<td>2 pts</td>
<td>Slight pink discoloration, darkened lips, goose pimpling.</td>
</tr>
<tr>
<td>3 pts</td>
<td>Reddening of face and neck, marbling visible on face, Possible early signs of animal activity/predation-concentrated on the ears, nose, and lips.</td>
</tr>
<tr>
<td>4 pts</td>
<td>Bloating of the face, green discoloration, skin beginning to slough off.</td>
</tr>
<tr>
<td>5 pts</td>
<td>Head hair beginning to slough off-mostly at the front. Brain softening and becoming liquefied. Tissue becoming exposed on face and neck. Green/black discoloration.</td>
</tr>
<tr>
<td>6 pts</td>
<td>Bone becoming exposed-concentrated over the orbital, frontal, and parietal regions. Some on the madible and maxilla. Early adipocere formation.</td>
</tr>
<tr>
<td>7 pts</td>
<td>More extensive skeletization on the cranium. Disarticulation of mandible.</td>
</tr>
<tr>
<td>8 pts</td>
<td>Complete disarticulation of the skull from torso. Extensive adipocere formation.</td>
</tr>
</tbody>
</table>

Descriptive stages for decomposition observed on the torso and the assigned body aquatic decompositional score (BADS) (from Heaton et al. (2010)).

<table>
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</thead>
<tbody>
<tr>
<td>1 pt</td>
<td>No visible changes.</td>
</tr>
<tr>
<td>2 pts</td>
<td>Slight pink discoloration, goose pimpling.</td>
</tr>
<tr>
<td>3 pts</td>
<td>Yellow/green discoloration of the abdomen and upper chest. Marbling. Internal organs beginning to decompose/autolysis.</td>
</tr>
<tr>
<td>4 pts</td>
<td>Dark green discoloration of abdomen, mild bloating of abdomen, initial skin slippage.</td>
</tr>
<tr>
<td>5 pts</td>
<td>Green/purple discoloration, extensive abdominal bloating-tense to touch, swollen scrotum in males, exposure of underlying fat and tissues.</td>
</tr>
<tr>
<td>6 pts</td>
<td>Black discoloration, bloating becoming softer, initial exposure of internal organs and bones.</td>
</tr>
<tr>
<td>7 pts</td>
<td>Further loss of tissues and organs, more bone exposed, initial adipocere formation.</td>
</tr>
<tr>
<td>8 pts</td>
<td>Complete skeletonization and disarticulation.</td>
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</tbody>
</table>
Descriptive stages for decomposition observed in the limbs and the assigned limb aquatic decompositional score (LADS) (from Heaton et al. (2010)).

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</tr>
<tr>
<td>2 pts</td>
<td>Mild wrinkling of skin on hands and/or feet. Possible goose pimpling.</td>
</tr>
<tr>
<td>3 pts</td>
<td>Skin on palms of hands and/or soles of feet becoming white, wrinkled, and thickened. Slight pink discoloration of arms and legs.</td>
</tr>
<tr>
<td>4 pts</td>
<td>Skin on palms of hands and/or soles of feet becoming soggy and loose. Marbling of the limbs-predominantly on upper arms and legs.</td>
</tr>
<tr>
<td>5 pts</td>
<td>Skin on hands/feet starting to slough off. Yellow/green to green/black discoloration on arms and/or legs. Initial skin slippage on arms and/or legs.</td>
</tr>
<tr>
<td>6 pts</td>
<td>Degloving of hands and/or feet-exposing large areas of underlying muscles and tendons. Patchy sloughing of skin on arms and/or legs.</td>
</tr>
<tr>
<td>7 pts</td>
<td>Exposure of bones of hands and/or feet. Muscles, tendons, and small areas of bone exposed in lower arms and/or legs.</td>
</tr>
<tr>
<td>8 pts</td>
<td>Bones of hands and/or feet beginning to disarticulate. Bones of upper arms and/or legs becoming exposed.</td>
</tr>
<tr>
<td>9 pts</td>
<td>Complete skeletonization and disarticulation of limbs.</td>
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## Appendix III. DATA

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<th>SEX</th>
<th>AGE</th>
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<th>TBS</th>
<th>HEATON ADD SCORES</th>
<th>TADS</th>
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VITA

Amanda Rose Fink was born in Fond du Lac, Wisconsin, where she lived until she graduated high school. She attended the University of Wisconsin-La Crosse and obtained a Bachelor of Arts degree in organizational and Professional Communication Studies, with a minor in Anthropology in 2012. She also obtained a Bachelor of Science degree in Archaeology in 2014. In 2014 she enrolled at the University of Tennessee Anthropology graduate school pursuing a degree in biological anthropology while focusing on forensic anthropology.