DECOMPOSITION IN CENTRAL TEXAS AND VALIDITY OF A UNIVERSAL POSTMORTEM INTERVAL FORMULA

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of ARTS

by

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San Marcos, Texas
August 201

DECOMPOSITION IN CENTRAL TEXAS AND VALIDITY OF A UNIVERSAL POSTMORTEM INTERVAL FORMULA

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ACKNOWLEDGEMENTS

I would like to thank the following people for their encouragement and support during my time at Texas State University-San Marcos:

Dr. Kate Spradley, my committee chair, for all your help and guidance over the past two years. Thank you for helping me develop this thesis into what it is today, and taking the time to help me with all my questions and concerns over the past two years.

Dr. Daniel Wescott, for all of your help with my thesis, as well as taking me on as your graduate research assistant. I appreciate all that you've helped me learn over the past two years.

Dr. Kerrie Graham, for working with my somewhat hectic and uncertain schedule. Thank you for your patience, support, and advice.

Sophia Mavroudas, for teaching me countless skills over the past two years, allowing me to gain experience in area of forensic anthropology that I wished, giving me all the opportunities that you did, and the encouragement.

Lauren Pharr, for your contribution of weather data and your friendship.

Ray Kamps, for you quick collation of my requested weather data.

Gabrielle Lavallo, Hailey Duecker, Cristina Watson, and the rest of my cohort: Thank you for your friendship, your help, and the shoulder to cry on and commiserate with.

My family, for always encouraging me and believing in me.

Lastly, thank you to all of the individuals and family members who have donated or will donate their bodies to the Forensic Anthropology Center at Texas State. Without their generosity, this research, as well as numerous other studies, would not be possible.

This manuscript was submitted on May 17, 2013.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Estimation of the length of time between death and discovery of human remains or the postmortem interval (PMI) can be one of the most important aspects of a forensic anthropological investigation. Previous researchers (Megyesi et al. 2005, Galloway et al. 1989, Galloway 1997, Vass 2011) have developed models to estimate the PMI using climate data and stages of decomposition. Vass (2011) developed a "universal" model for estimating PMI based on a longitudinal study of human decomposition in east Tennessee. However, the Vass (2011) model has not been tested on human remains outside of Tennessee. Research has demonstrated that the decomposition process is highly dependent on regional and local (exact location of remains found) environmental conditions (Mann et al. 1990). Due to the close relationship between the environment and decomposition, it may be unrealistic to assume that a universal model can be developed (Parks 2011). Instead, climate region or even state-specific models are more likely to provide more accurate results (Parks 2011). Because of this, it is important that any new methodology related to human decomposition be validated through testing on human subjects. The purpose of this study is to test the accuracy of the Vass (2011) model of PMI on a large sample (40 individuals) of human remains allowed to naturally decompose in Central Texas. In addition, this study will attempt to establish baseline PMI data for Central Texas that will allow for the development of a more accurate model when estimating the PMI.

Literature Review

Decomposition

The postmortem interval is often described in progressive stages of decomposition: fresh, early decomposition, advanced decomposition, skeletonization, and extreme decomposition (Galloway et al. 1989, Galloway 1997). The fresh stage occurs immediately after death, before any visible decomposition or insect activity has occurred. Early decomposition is characterized by skin slippage, discoloration of the skin that is typically green, grey, red, or black (often referred to as marbling), and bloating of the body due to the buildup of gasses. Advanced decomposition occurs when the abdominal cavity collapses as gasses are released and fluid begins to purge from the body. The appearance of adipocere and mummification of the skin also occur during advanced decomposition. Skeletonization occurs when at least half of the skeleton is exposed, although the bones might retain a greasy or moist appearance. The last stage of decomposition according to Galloway et al. (1989) is extreme decomposition, which is characterized by bleaching and drying out of the bones, and the loss of remaining soft tissue.

Previous researchers have examined the decomposition process to establish a model for estimating the PMI (Megyesi et al. 2005, Galloway et al. 1989). However, most of these studies have focused on the short-term decomposition process. Large sample studies of longitudinal decomposition have been performed, but most have involved the use of animals, like pigs, as the study subject or partial human remains (Hyder 2007, Ayers 2010). Long-term studies of decomposition should be tested with human cadavers, as pig decomposition rates cannot be directly applied to human decomposition (Shirley et al. 2011). The following section describes three models of human decomposition based on relatively large cross-sectional samples of human remains.

Galloway et al. (1989) Model

Galloway et al. (1989) used a sample of 189 forensic cases in southern Arizona to study the decay rates and decomposition processes of human individuals. They were able to establish five main stages of decomposition, with characteristics of each stage of decomposition listed and relative time frames provided for each stage (Table 1). In general, they found that bodies found outside exhibited accelerated decomposition, and that insect activity accelerates the decomposition process.

While these descriptions have been very useful in medicolegal investigations, the data used for this study were comprised of individuals from cross-sectional forensic cases. Because of this, no longitudinal data were used for the study and many variables could not be controlled.

Table 1: Stages and Descriptions of Decomposition

Stage	Description
Early Decomposition/Bloat	Skin slippage, hair loss, skin discoloration, maggot activity, bloat, and post-bloat including possible rupture of abdominal gases.
Late Decomposition/Decay	Sagging of the flesh following post-bloat, caving in at the abdominal cavity, continued maggot activity, decomposition of tissue, exposure of bone, purge.
Mummification/Decay	Complete drying out of soft tissue, retention of skin in dried, leathery state.
Skeletonization/Dry	Complete exposure of bone, some soft tissue still attached.

Megyesi et al. (2005) Model

Megyesi et al. (2005) published a cross-sectional model for estimating the postmortem interval, which combines the calculation of accumulated degree-days with a total body score to estimate the postmortem interval (Megyesi et al. 2005). Accumulated degree-days (ADD) refer to a formula that calculates the total number of heat energy units that have been produced since death that could propel biological process, like bacterial or insect growth (Megyesi et al. 2005). The case files of 68 individuals taken from the authors' files were used for the study. They found that decomposition should take into account temperature as well as time since death, and cautioned that only 80% of decomposition can be accounted for using ADD.

The Megyesi et al. (2005) model was tested in Central Texas by Suckling (2011) with a relatively small sample size (10 individuals). Suckling used longitudinal data collected at the Forensic Anthropology Research Facility at Texas State University-San Marcos to determine if decomposition occurred in the sequential order claimed by Megyesi et al. (2005). Suckling (2011) found a significant difference between actual ADD and expected ADD, and argued that this might be in part due to an inability to account for certain environmental variables that are not incorporated into the study by Megyesi et al. (2005).

Vass (2011) Model

Vass (2011) is the only published study of longitudinal decomposition involving a "large sample" of human individuals, although the exact sample number is unknown. It is also the only published universal postmortem interval model. The Vass model appears to fill the gaps that exist in our understanding of the decomposition process. Vass (2011) used decomposition data collected from the Forensic Anthropology Facility at the University of Tennessee (UT)- Knoxville. Climate data collected from a weather station at the facility were analyzed to create an environmental constant for the postmortem interval formula. The formula takes into account average temperature, average humidity, percentage of decomposition, and a constant of 1285 accumulated degree-days. This constant is explained as the amount of time it takes for soft tissue to completely decompose, and was calculated by Vass in a previous study (Vass et al. 1992). He provides a few examples of the application of his formula and it appears to provide a roughly accurate PMI.

The Vass (2011) universal model is a necessary model for the discipline, but it has never been formally tested or validated. Furthermore, there are several problems with reproducing the Vass method and determining its validity. First, Vass does not state the sample size used in the development of his formula, or provide adequate information regarding how he scored decomposition or developed his formulae. Second, the samples used in the Vass (2011) study all decomposed in wooded regions of East Tennessee at the University of Tennessee (UT). Some of the cadavers at UT are also placed lying facedown under tarps, which accelerates the decomposition process by acting as a heat-retainer (Mann et al. 1990).

A universal model for estimating PMI is ideal. However, research has demonstrated that the decomposition process is highly dependent on regional and local (exact location of remains found) environmental conditions (Mann et al. 1990). Due to the close relationship between the environment and decomposition, it may be unrealistic to assume that a universal model can be developed (Parks 2011). Instead, climate region or even state-specific models are more likely to provide more accurate results (Parks 2011). Because of this, it is important that any new methodology related to human decomposition be validated through testing on human subjects.

Statement of Purpose

This study involves a longitudinal examination of human decomposition on a large sample (n = 40) of human remains to tests the accuracy of the Vass 2011 model of PMI. In addition, this study attempts to establish a baseline PMI dataset for Central Texas that can be used to develop a more accurate model for estimating PMI in this unique region. The study will specifically address the following:

1. Test the validity of the Vass method by examining the accuracy and bias of the calculated PMI with known PMI from Central Texas. Statistical significance will be evaluated using a t-test.

2. Establish a baseline PMI for Central Texas.

   The baseline will be established by examining the minimum and maximum ADD for each of the major stages of decomposition. The baseline will also examine if the donations go through the stages of decomposition in a linear manner or if there are frequent deviations.

II. MATERIALS AND METHODS

Materials

This study took place at the Forensic Anthropology Research Facility (FARF), a fenced-in five-acre plot of land for the study of human decomposition. The facility is located in Freeman Ranch on Texas State University land located outside of the main city. The facility contains both shaded and direct sunlight areas for placement of donations, with an area in the middle of the facility designated for vulture scavenging research.

Donations

A total of 40 donated human cadavers were used for this study. The donated individuals were part of the willed body program run through the Forensic Anthropology Center at Texas State (FACTS). The Forensic Anthropology Center is one of only four human decomposition facilities in the United States. Its mission is to "advance forensic science and anthropology through world-class education, research, and outreach" (FACTS 2012). The Forensic Anthropology Research Facility (FARF), located at Freeman Ranch in San Marcos, TX allows graduate students to conduct research on many topics related to forensic anthropology, including decomposition.

Donations are received in two ways: 1) living donors who have completed a living donor questionnaire and release form, and 2) next-of- kin donations where family members donate the remains of a recently deceased individual. Donors can be of any age, sex, ancestry, or health condition, provided that they do not have any communicable diseases and weigh less than 500 pounds. Donations at the facility can be autopsied, organ donors, or individuals who are missing a limb or other element.

Once the donation has been collected, the donor is taken to the processing laboratory, where blood, hair, and nail samples are collected, donation number tags fastened to each limb, and vital statistics recorded. Once the intake process is completed, the donors are taken to the research facility at Freeman Ranch, where they are placed face-up in standard anatomical position and covered with a wire cage to prevent large mammal and avian scavenging.

Data from both past donations (Suckling 2011) and current were included in the study to attain as large a sample size as possible. At the time this study was conducted, FACTS had received 25 males and 15 females that were viable for this study. Donations ranged in age from 19 to 101 years of age for this study (Figure 1). Donated individuals were primarily White in ancestry, with only 1 individual classified as Black and 1 more as Other (Asian).

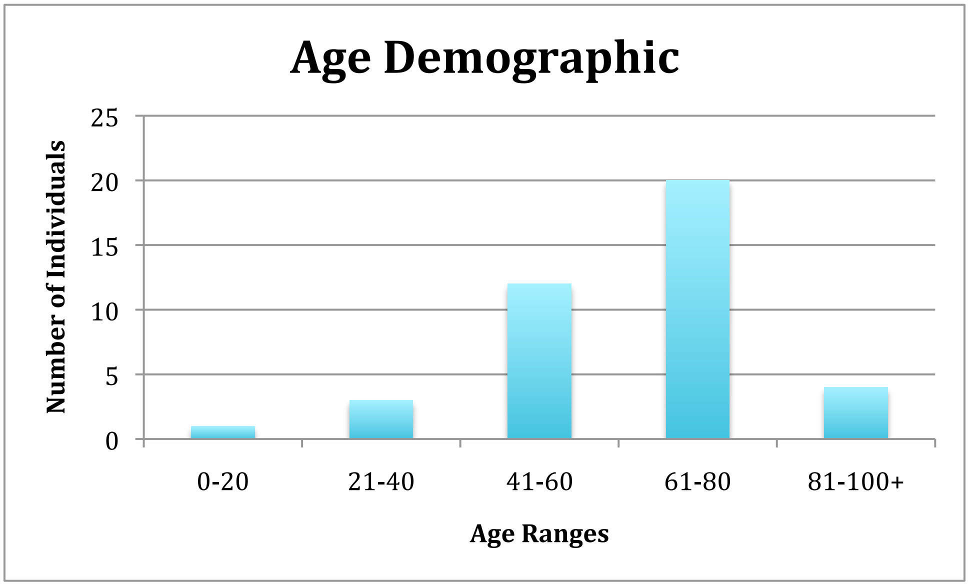

Figure 1: Age Distribution of Donations Used in This Study

According to Vass (2011), age and sex should not affect the calculations of PMI based on his formulae, so a non-uniform sample should not adversely affect my study. Although the donated cadavers were in varying states of health at the time of death, Vass (2011) did not state that this would have any bearing on the postmortem calculation. Therefore, this study did not control for age, sex, or cause of death in the decomposition process.

Environment

FARF is located in Freeman Ranch in San Marcos, TX. This area of central Texas is described as a humid sub-tropical climate, prone to period droughts and floods (Dixson 2000). The average temperature is 60°F with highs above 100°F and lows averaging 40°F in winter (Dixson 2000).

The facility itself is characterized by tall grass and small groupings of dense tree foliage. The donations that are not buried are placed in cages that leave them exposed to the elements, including extreme heat and precipitation.

Methods

Observations of Decomposition in Central Texas

Once the cadavers had been placed at the research facility, photos were taken every day for a month and every other day thereafter to track the decomposition process. Photos were initially taken daily due to the rapid decomposition that occurs in the early postmortem period. As decomposition retarded towards the end of early decomposition and into late decomposition, photos could be taken every other day. Photos were taken with two Nikon D-series cameras and daily notes recorded in a binder with a section for each donation. The photos and notes were compiled into digital folders for each individual and these folders were used to assess the rate of decomposition.

For this study, the stages of decomposition that were scored were fresh, early decomposition, late decomposition, mummification, and skeletonization. These stages are an incorporation of descriptions provided by both Galloway et al. (1989) and Vass (2001).

Fresh refers to the body at time of death, before visible decomposition has commenced. Early decomposition, like previously stated, is scored when discoloration, bloat, and skin slippage are seen (Figure 2). Late decomposition is characterized by a sunken abdomen, purge of fluid from the body, adipocere formation, loss of mass, and the initial drying out of the skin (Figure 3). Mummification is viewed as dry soft tissue, with no visible liquid retained (Figure 4). Skeletonization refers to the visibility of the entire skeleton (Figure 5).

Figure 2: Example of Early Decomposition at FARF.

Figure 3: Example of Late Decomposition at FARF.

Figure 4: Example of Mummification at FARF.

Figure 5: Example of Partial Skeletonization at FARF.

Baseline Postmortem Interval for Central Texas

As a result of the data collected during the course of this study, a baseline postmortem interval was created for Central Texas. The baseline postmortem interval was calculated by finding the minimum and maximum number of days observed to reach each stage of decomposition, provided in both actual days and accumulated degree-days. This is not a comprehensive postmortem interval by any means, and is meant only as an initial observation of decomposition in Central Texas.

Accumulated Degree-Days

The observed postmortem intervals for each stage of decomposition are described in terms of accumulated degree-days. Accumulated degree-days were calculated using the method published by Edwards et al. (1987). Accumulated degree-days "represent heat energy units available to propel a biological process such as bacterial or fly larvae growth" rather than merely the number of actual days of decomposition (Megyesi et al. 2005:4). This allows for a more accurate representation of decomposition that takes temperature data into account. Accumulated degree-days were calculated by summing the average daily temperatures above 0°C from date of placement until stage completion. Temperature and relative humidity data were collected and provided by Lauren Pharr, Louisiana State University, and Ray Kamps and James Heilman, Texas A&M University. The weather sensors were connected to a Hobo Micro Station (Onset Computer Corporation 2010) and programmed to record minute samples 24-hours per day as part of a long-term vulture-scavenging project (Pharr 2011). Sophia Mavroudas, FACTS, interpolated the data to daily averages using R statistical software (R Development Core Team 2008).

Universal Postmortem Interval Formula

Vass (2011) uses a percentage of decomposition in his study, but does not provide a clear method for how he determined the percentage of decomposition, stating only that an experienced forensic anthropologist should score the body. He does reference a publication by Rodriguez and Bass (1983), however the ranges are dry versus wet, and were collected in a potentially different environment. Additionally, the decomposition stages provided by Galloway et al. (1989) are more clearly defined and the model more widely used. Therefore, in this study, I used the following percentages for each stage of decomposition, using a combination of Galloway et al. (1989) and Vass (2011). For each stage, I used the decomposition percentage range provided by Vass (2011) and incorporated the decomposition stage descriptions provided by Galloway et al (1989):

Fresh = 0% - 24%

Early = 11%-45%

Advanced = 36%-85%

Mummification = 85%-100%

Skeletonization = 100%

As the Vass formula provides a point estimate for the postmortem interval, and a standard error rate is not provided, I calculated both the minimum and maximum expected postmortem intervals of each stage of decomposition using the percentage range provided in Vass (2011).

Once decomposition was complete, Vass' equation was calculated for the first day of each new stage of decomposition (Vass 2011):

Formula 1 (PMI aerobic): $$\frac{1285 \times (\text{decomposition}/100)}{0.0103 \times \text{temperature} \times \text{humidity}}$$

Formulas were only recorded for the date of each new stage of decomposition due to the large sample size and amount of formulas required. The transition to a new stage was determined by the presence of most or all descriptions of the current stage of decomposition provided by Galloway et al. (1989) and an apparent transition to the next stage of decomposition. Decomposition was scored following Vass' (2011) formula using on a scale from one to a hundred based on soft tissue decomposition. A t-test was used to test if the Vass model accurately estimates PMI in Central Texas by examining the difference between the expected and actual postmortem intervals.

Intra-Observer Error

Intra-observer error in decomposition stages was accounted for by selecting a random assortment of decomposition photos that underwent a second round of scoring based on the criteria listed above for each stage. The results of the second observation were compared with the original scores to see if a significant difference existed in intra-observer error and bias. The results of the first observation were not visible during retesting and did not influence the second round of scoring.

Possible Confounding Variables

Although Vass (2011) does not address it in his study, it is possible that the different conditions of the donations at time of placement might affect decomposition rates. FACTS accepts donations from individuals that are both autopsied and non-autopsied, and will accept individuals with any cause and manner of death as long as they do not carry a contagious disease. This means that many of the donations are placed at the facility in various forms of trauma and causes of death. It is quite possible that the disparity in the condition of the bodies at placement might skew this study as, though the donations at the University of Tennessee are received in a similar manner, Vass does not discuss what his criteria was regarding what donations constituted an acceptable donation for his study. It is unknown whether these factors might have skewed his own study.

Additionally, as Vass 2011 does not include seasonal effects and many other variables aside from temperature and humidity, it is possible that my results were skewed by any number of confounding variables.

III. RESULTS

Observations of Decomposition in Central Texas

Decomposition at FARF appears to correspond with the findings of Galloway et al. (1989). The majority of the donations exhibited rapid decomposition in the earlier stages of decomposition, beginning as early as two days after placement, with skin slippage and large maggot and fly activity followed by extreme purge. This was quickly followed by advanced decomposition and mummification, at which point the donations generally entered a retarded rate in decomposition. Only one donation included in the study, D05-2010, reached full skeletonization.

Most donations exhibited bloat and extreme odor, adipocere formation, and multi-colored mold growth during early to advanced decomposition. Discoloration did not manifest in a uniform manner, appearing at different intervals and areas of the body, in different colors. These matched observations made by Suckling (2011), but did not follow the decomposition observed by Megyesi et al. (2005) or Galloway et al. (1989).

Some of the donations exhibited slight rehydration following rainfall, which was previously observed by Ayers (2010) and Suckling (2011), however this does not appear to have significantly altered decomposition.

Early decomposition was observed between thirty-four and three hundred and two ADD after placement at the facility. Late decomposition was observed between two hundred and thirteen (213) and seven hundred and eighty-four (784) ADD after placement. Full mummification was observed between two hundred and forty-one (241) and one thousand six hundred and ninety-eight (1,698) ADD after placement. The only observable case of full decomposition was observed one thousand three hundred and eighty-three (1,383) ADD after placement (D05-2010) (Figures 6 and 7).

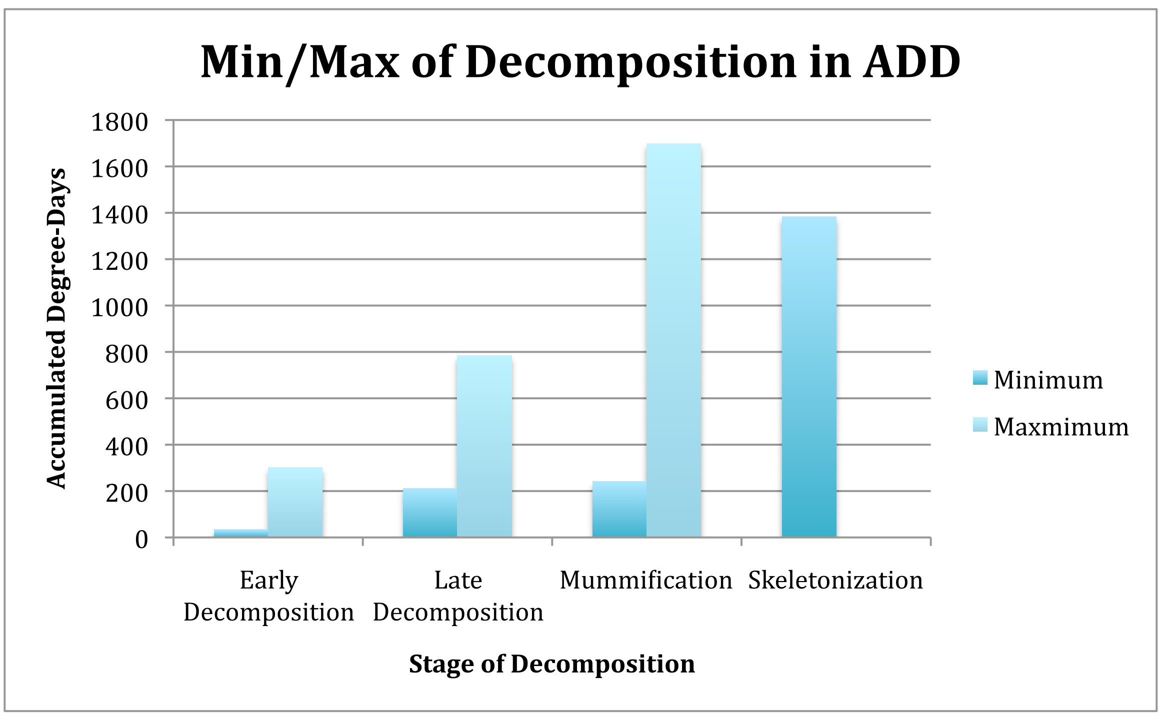

Figure 6: Decomposition Ranges at FARF in Accumulated Degree-Days

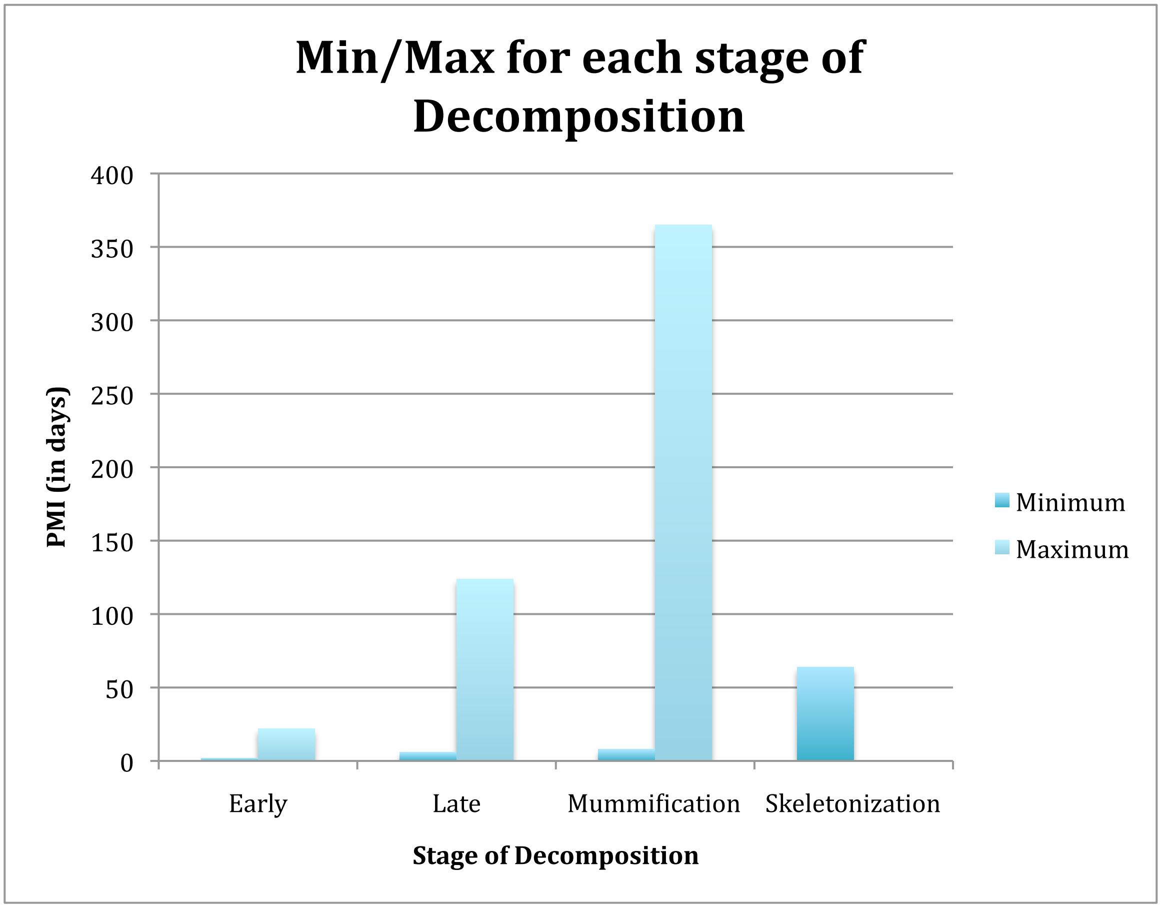

Figure 7: Minimum and Maximum Number of Days for Each Stage of Decomposition

Universal Postmortem Interval Formula

The postmortem interval was calculated for each donation at each stage of decomposition. A comparison of the expected postmortem interval to the actual postmortem interval shows that the expected postmortem interval is consistently overestimated for donations at the facility. All results are reported in days, rather than ADD, due to the requirement of actual days in the Vass formula.

Expected postmortem interval values exceeded estimated values by between six days (D14-2012) and fifty-four days (D14-2010) for the stage of early decomposition. Expected values exceeded actual postmortem interval values by between five days (D08-2012) and one hundred and two days (D14-2010) for late decomposition. For the mummification stage of decomposition, expected values for the postmortem interval exceeded actual values by between six days (D09-2011) and one hundred and seventeen days (D03-2011).

The actual values were compared against the expected values for each stage of decomposition and a t-test performed. The results showed a significant difference for each stage of decomposition, with the most significant difference occurring in the early stage of decomposition. There was significant variation between the actual and expected postmortem interval for the minimum range of early decomposition (p-value=0.0005) and the maximum range of early decomposition (p-value=3.97×10^{-11}) (Figure 8) (Table 2).

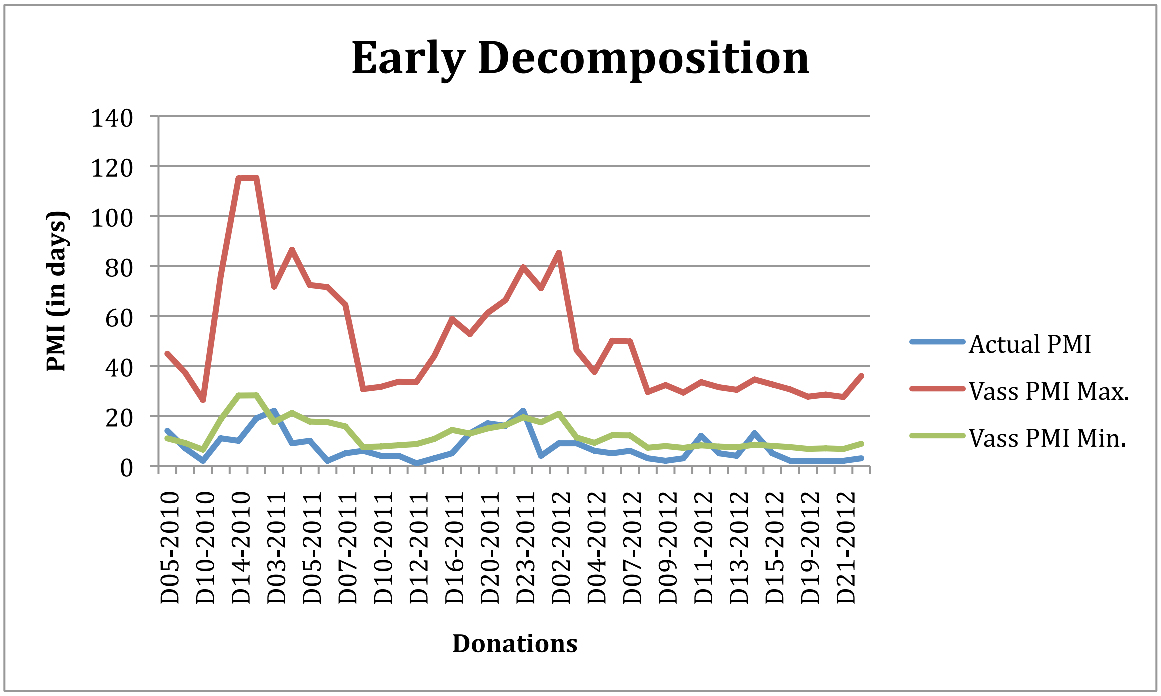

Figure 8: Actual Verses Expected Rates of Early Decomposition at FARF

Late decomposition also showed a significant difference between the expected and actual postmortem interval estimate for both the minimum and maximum range of late decomposition. The maximum range of late decomposition showed greater variation (p-value=$4.7x10^{-13}$) than the minimum range (p-value=$2.3x10^{-5}$) (Figure 9) (Table 2).

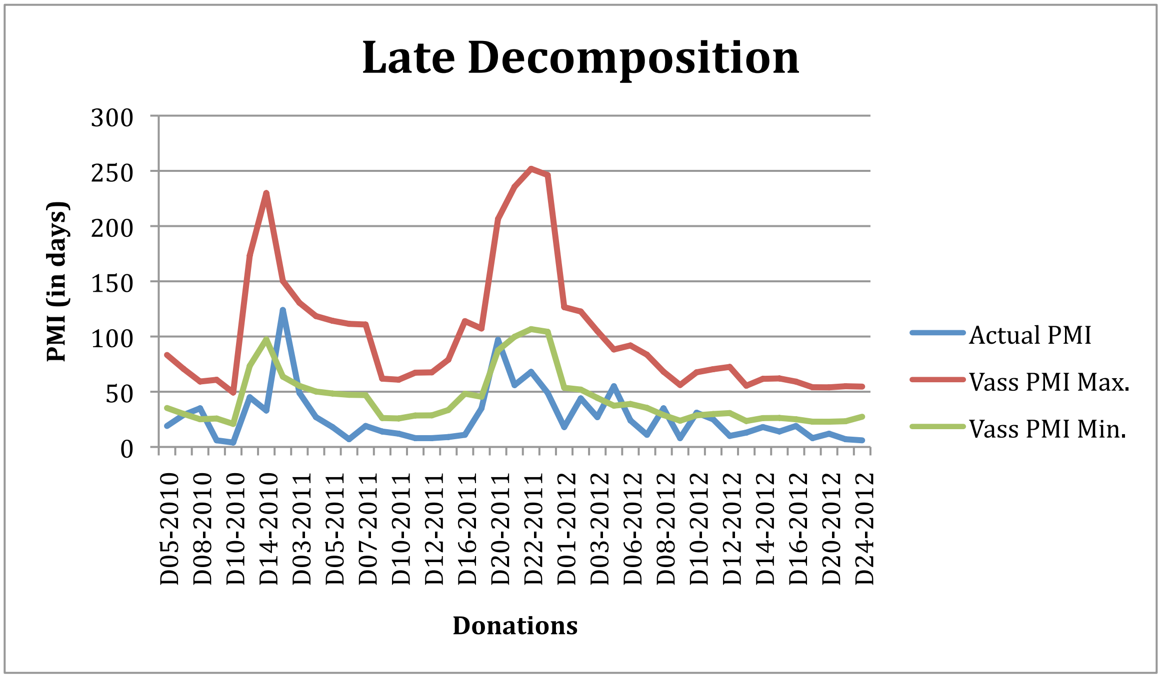

Figure 9: Actual Verses Expected Rates of Late Decomposition at FARF

Mummification also showed a significant difference between the expected and actual postmortem interval estimate for both the minimum and maximum range of mummification (86% and 100%). The maximum range showed greater variation (p-value=$2.54x10^{-5}$) than the minimum range (p-value=0.001) (Figure 10) (Table 2).

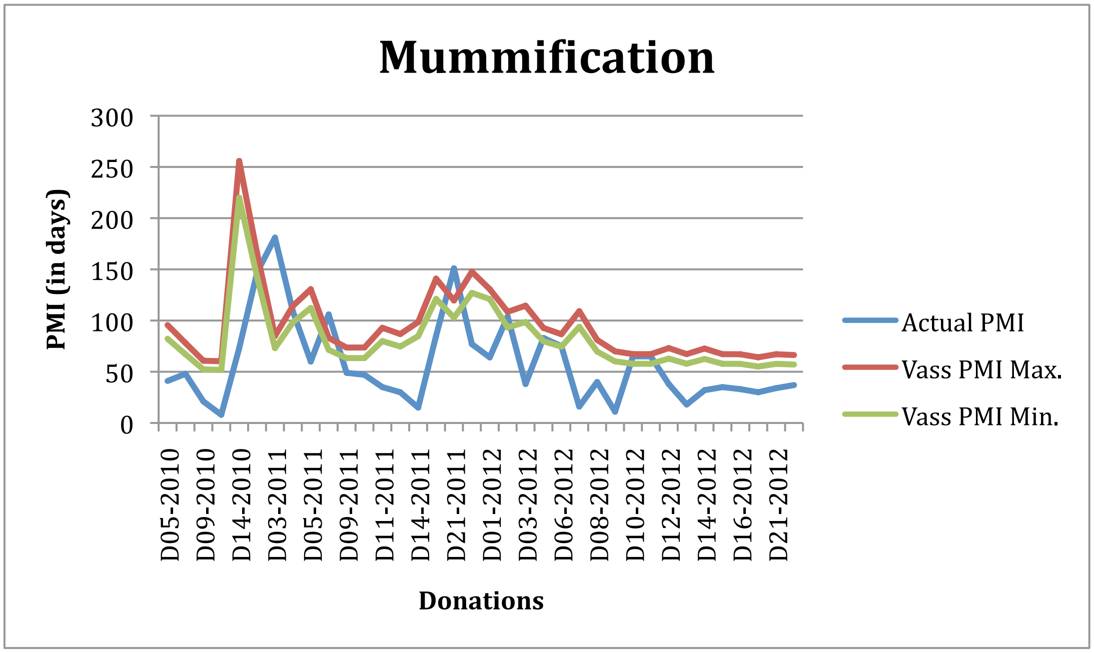

Figure 10: Actual Verses Expected Rates of Mummification at FARF

Table 2: Results of the T-test for Each Stage of Decomposition

Stage of Decomposition	P-Value (min)	P-Value (max)
Early Decomposition	0.0005	$3.97x10^{-11}$
Late Decomposition	$2.3x10^{-5}$	$4.7x10^{-13}$
Mummification	0.001	$2.54x10^{-5}$

Intra-Observer Error

Intra-observer error was calculated by re-sampling five of the forty donations used in this study. Each of the five donations was scored once again for each stage of decomposition. The observed values were tested for significance using a t-test. Significant differences between observations were not found for either the early or late stage of decomposition (p-value= .828 and .235), however the observations of mummification did exhibit significant variation (p-value= .019) (Table 3).

Table 3: Intra-Observer Error

Donation	Early Decomposition		Late Decomposition		Mummification	
	Score 1[1]	Score 2[2]	Score 1	Score 2	Score 1	Score 2
D13-2012	4	4	13	9	18	60
D14-2012	13	10	18	17	32	61
D15-2012	5	6	14	12	35	70
D16-2012	2	4	19	19	33	60
D21-2012	2	3	7	8	34	35
D13-2012	4	4	13	9	18	60
D14-2012	13	10	18	17	32	61

[1] Score 1: Denotes the actual PMI score (in days) found for the donation during the initial analysis.
[2] Score 2: Denotes the actual PMI score (in days) found for the donation during resampling.

IV. DISCUSSION

The purpose of this study was two-fold. First, the study sought to test the validity of the universal postmortem interval formula published by Vass (2011) in an environment outside of Tennessee. Second, the study provides data regarding stages of decomposition and known PMI to serve as a baseline postmortem interval for Central Texas. While this study consists of the largest sample of human longitudinal data to be studied in Central Texas to date, this study presents only preliminary results regarding the human decomposition sequence in Central Texas. It does not take all of the variables that could affect decomposition into account, including seasonality, condition of the body, placement of the body (sun vs. shade), and whether the individual was autopsied.

Decomposition in Central Texas

Observations of decomposition at FARF appear to support previous studies conducted at the facility (Hyder 2007, Ayers 2010, Parks 2010, Suckling 2011), and follow the decomposition sequence for arid environments detailed by Galloway et al. (1989). Donations at FARF exhibit high maggot and insect activity, similar to the findings of Hyder (2007), Ayers (2010), and Suckling (2011). Accelerated decomposition was also observed, similar to Suckling (2011), although decomposition generally retarded during cooler months.

Discoloration was observed in all donations at FARF, however the date of appearance, patterning, and colors varied by individual and did not appear to follow the same sequence in every donation. Over half of the donations also exhibited some form of mold growth during the course of early and advanced decomposition, which was not typically found in previous studies (Galloway et al. 1989, Megyesi et al. 2005). The mold growth differed in color, size, texture, and orientation on the body. No general pattern was detected for the mold, although further research should be conducted on the subject.

Once advanced decomposition had occurred, donations generally entered into an extended period of mummification. While rehydration occured in a few of the donations once they had reached mummification, as a result of rainfall, this did not appear to significantly alter the decomposition process of the individual, and mummification returned in a manner of days. It should be noted that mummification is still relatively unknown, and it is unclear how decomposition is altered by mummification, or the potential effects of the rehydration process.

Unlike the study by Suckling (2011), only one individual in this study reached complete skeletonization, while another six exhibited only partial skeletonization. All ten donations included in Suckling's thesis reached full skeletonization, with the earliest full skeletonization occurring twelve days after placement and the latest full skeletonization occurring ninety-four days after placement.

In instances where partial skeletonization was present, this was largely observed on the skull, distal appendages, and upper torso, while all other regions remained mummified. It is likely that these elements reached skeletonization due to the relatively thin tissues present in those areas. The skull and distal appendages have very little fat content or excess tissue, which tend to result in accelerated decomposition, and the sternum and clavicles are anteriorly positioned in the torso, with less soft tissue present than in other areas of the torso region.

Universal Postmortem Interval Formula

The main objective of this study was to test the validity of the Vass (2011) universal postmortem interval formula in Central Texas. Results from the t-test comparison of the actual postmortem interval and estimated postmortem interval were significantly different in all categories of decomposition, at both the lower and upper percentage range for each stage. The results of the t-test show that the postmortem interval formula published by Vass (2011) does not accurately estimate the postmortem interval for decomposition in Texas, but consistently overestimates the postmortem interval. As such, it is not recommended that this formula be used to estimate the postmortem interval in Central Texas without adjustment at this time.

Although Vass (2011) does not provide a standard error or range that can be used to determine if the data still falls within the normal distribution of two standard deviations, it is clear based on the graphs (Figures 8, 9, 10) that the collected data and Vass' formulated data follow the same trend or pattern. Although the PMI calculations are overestimated, the peaks and dips in the graphs do occur at roughly the same point for both the actual and expected PMI's. Because of this, it might be possible to adjust the formula to fit various climates if relevant weather data can be acquired.

There are a number of factors that could have influenced these results, but they were not accounted for in this study, largely due to the exclusion of the variables by Vass (2011) of the formula. One variable that is not accounted for is the condition of the body at time of placement, i.e. autopsied or complete and presence of traumatic wounds. Vass does briefly mention that a body should be intact, however, he does not state to what extent, and states that insect access does not affect the formula (Vass 2011). It is important to note, however, that when a body exhibits some sort of trauma, whether perimortem or postmortem, insect colonization is accelerated (Cross and Simmons 2010). As this formula is intended for use in a forensic setting, wherein traumatic wounds are expected, autopsied individuals and individuals with perimortem trauma were included in this study.

Weight, age, relative health, and cause and manner of death are also not explored in Vass 2011, except to state that adipocere formation should be sparse on the body for the formula to work. While it is possible that these factors do not significantly alter the decomposition rate, it would be advantageous to explore these factors in depth, especially manner of death. If an individual was ill at the time of death there will likely be chemicals present in the body that could affect decomposition, as those chemicals have the potential to interact with naturally occurring chemicals in the body and alter the bodies chemical breakdown process.

Additionally, although both Tennessee and Texas are classified as humid, sub-tropic climates, discrepancies exist in the average amount of annual rainfall. Central Texas is also more prone to a drought than Tennessee, and this affects average humidity and temperature. It is likely that the difference in average temperature and humidity accounts for at least part of the discrepancy between actual and expected postmortem intervals as predicted by the formula. Temperature and humidity are the only two variables that are necessary to the postmortem formula aside from percentage of decomposition. This means that any differences in climate have the potential to largely influence the results of the formula. Additionally, the constant of 0.0103 used in the formula is stated to be the slope of a regression equation involving average humidity levels in Tennessee collected over many years. With the differences in average humidity between Tennessee and Texas, it is likely that this constant would need to be adjusted in order for the formula to accurately reflect Central Texas climate patterns.

To determine if adjusting the slope would provide more accurate results, I calculated a new slope based on the average daily humidity levels that I had acquired for my thesis. I then substituted the new slope, calculated as 0.0356, into the Vass formula and re-calculated all of my data. The resulting calculations resulted in a reduced variation between the estimated and actual postmortem interval, however the results were still significantly different in all but one calculation. As the results appear to remain biased, although now in the form of underestimation of the PMI, it is apparent that further adjustments would be necessary. It is also possible that another calculation would be able to better account for the variation in decomposition, especially if it included additional data, rather than only temperature and humidity levels.

With the new formula, variation between expected and actual decomposition at minimum early decomposition was reduced to around four days (p-value $=1.34\text{x}10^{-5}$) and thirteen days (p-value$=2.64\text{x}10^{-5}$) at maximum early decomposition, on average (Figure 11). Variation between expected and actual decomposition at minimum late decomposition was reduced to around fifteen days (p-value $=3.68\text{x}10^{-5}$) and three days (p-value=0.54) at maximum late decomposition, on average (Figure 11). It should be noted that the p-value for maximum late decomposition was not significant (Figure 12). Variation between the expected and actual decomposition at minimum mummification was reduced to thirty-five days (p-value$=3.91\text{x}10^{-6}$) and twenty-nine days (p-value$=2.53\text{x}10^{-5}$) for maximum mummification (Figure 13). The results still depict a significant difference between the expected and actual PMI, however this is reduced and the estimations are now more similar.

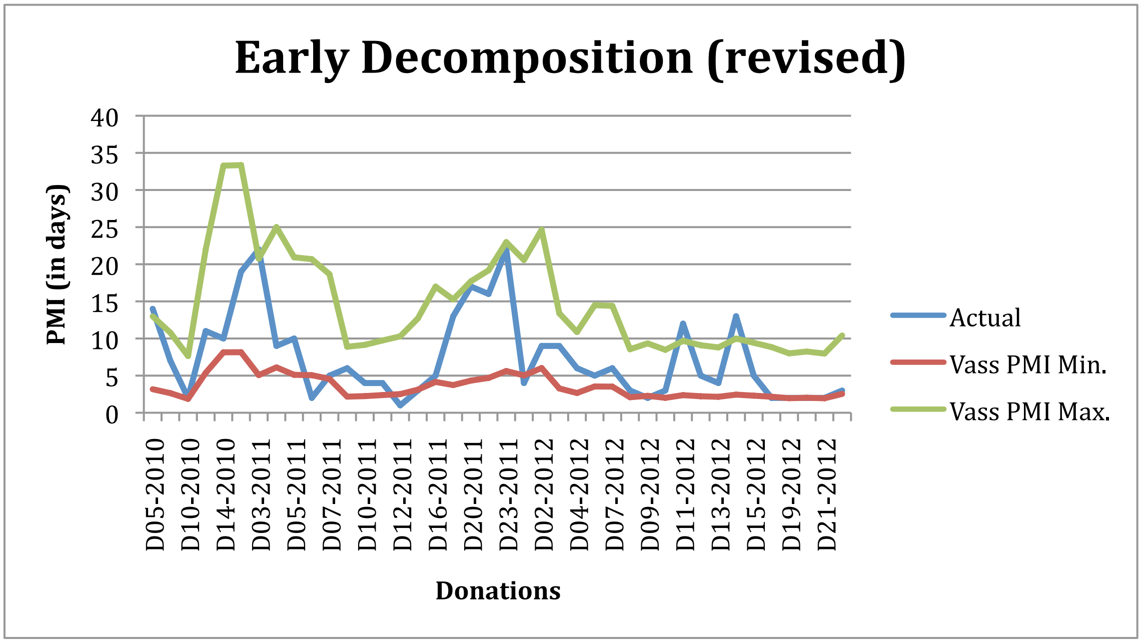

Figure 11: Actual Verses Expected Rates of Early Decomposition at FARF With New Slope. The Vass PMI min and max are calculated with a slope of 0.0356 instead of 0.0103.

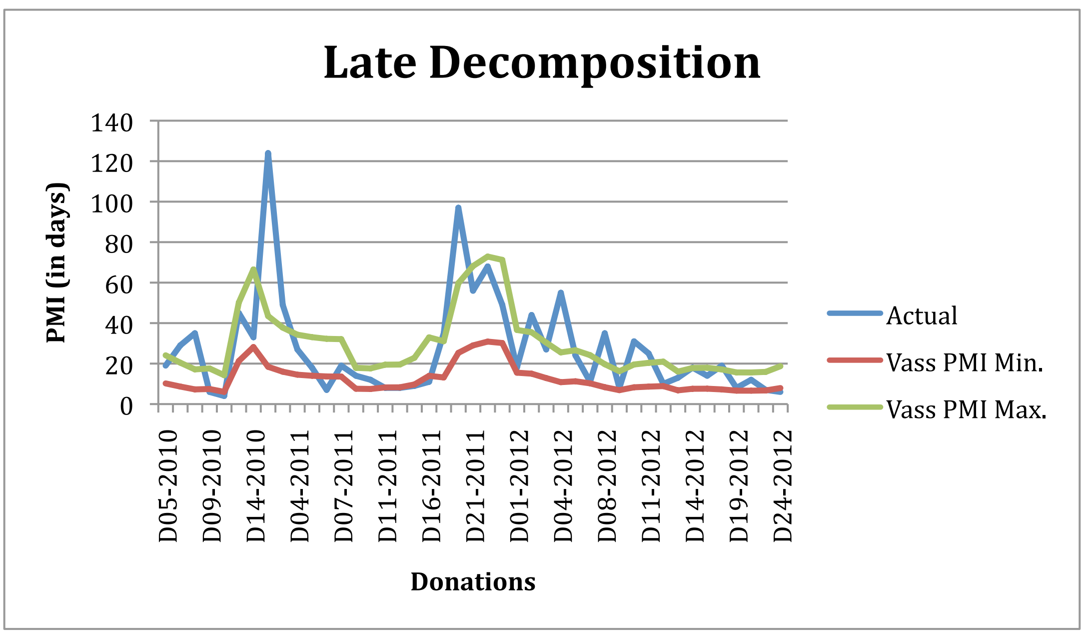

Figure 12: Actual Verses Expected Rates of Late Decomposition at FARF with New Slope. The Vass PMI min and max are calculated with a slope of 0.0356 instead of 0.0103.

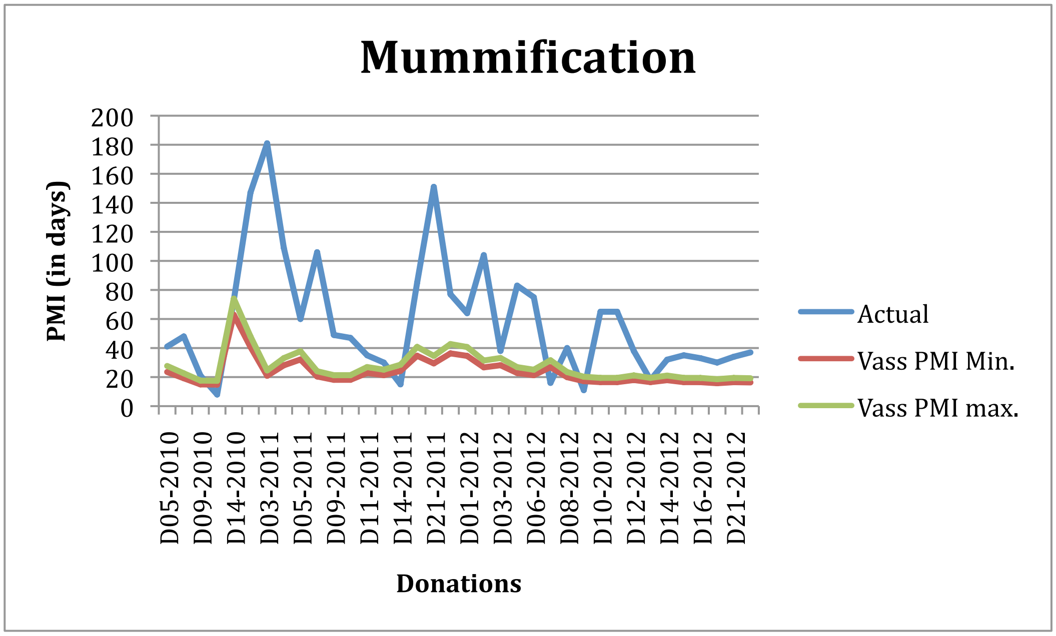

Figure 13: Actual Verses Expected Rates of Mummification at FARF with New Slope. The Vass PMI min and max are calculated with a slope of 0.0356 instead of 0.0103.

It appears that, with an adjusted slope and the inclusion of a standard error rate, the formula published by Vass might be applicable to an environment outside of Tennessee. It is important to remember that mummification is highly variable, however, and will likely always result in calculations that are not exact, which raises the question of whether mummification is actually of use in estimating the PMI.

Even with an adjusted formula, however, some problems still remain. The scoring system of the Vass formula is ambiguous. While Vass does mention the potential use of Rodriguez and Bass (1983) as a guide for decay rates, it is more common today to use Galloway et al. (1989), especially in a similar arid environment like Texas. While the Rodriguez and Bass (1983) method does include stages of decomposition, it focuses on insect activity and the types of insect found during each stage of decomposition, not all aspects of decomposition. Additionally, the studies were conducted in two different environments, so there is a difference in the duration period of each stage. Because of this, it is not as easily accessible as the Galloway et al. (1989) method, which provides descriptions of visual cues to denote each stage of decomposition and mentions the potential complications that result from various forms of insect activity. The use of a percentage scale from 1 to 100 to score decomposition by Vass (2011) is additionally problematic, as decomposition stages do not actually always imply a sequence of events according to Galloway et al. (1989), and modifications do occur. Mummification in particular has the potential to drastically alter decomposition scoring, as observed by the donated individuals at FARF. The inclusion of a total body score like one used by Megyesi et al. (2005), rather than a percentage of decomposition, might prove to serve as a more accurate barometer of decomposition, since the body does not decompose in a uniform manner.

It should also be noted that the potential exists for observer error to affect the results, as shown by the intra-observer error t-test. Although early and advanced decomposition observations did not differ significantly, significant variation was observed in the mummification stage of decomposition. This might have been caused by the arrested state of decomposition once the body reached the mummification stage. Although Vass advises that observers be "skilled" in decomposition, the brief instructions for ranking decomposition might not be enough to produce a standard enough method that would provide repeatable results. More research is needed to better describe mummification, but this is beyond the scope of the current project.

While the variables listed above have the potential to reduce the accuracy of the postmortem interval formula, it should be noted that the actual and expected postmortem intervals did appear to follow the same general trend. It is entirely possible that, with the inclusion of the previously discussed variables, and adjustments made for local climate data, the universal postmortem interval formula could produce valid results. Additionally, there has been no real discussion within the literature over what constitutes an appropriate range for a postmortem interval or how accurate a formula would need to be. It is possible that this formula could be considered valid, even with the consistent overestimation of a postmortem interval, especially if an acceptable range is considered to be months or even years, rather than days. An acceptable range for a stage like early decomposition is likely to be drastically different from an acceptable range for mummification or skeletonization, as the decomposition process is accelerated in the early stages of decomposition and gradually declines as time elapses. Further studies and an in depth discussion are required before an acceptable range can be established.

V. CONCLUSION

Estimating the postmortem interval is a vital but complicated aspect of death investigation. Climate, temperature and humidity, in particular, are considered to be the most important aspects of postmortem interval estimation (Mann et al. 1990, Love and Marks 2003). Because of this, many researchers (Galloway et al. 1989, Vass et al. 1992, Komar 1998, Rhine and Dawson 1998) have discussed the need for region-specific postmortem interval methodologies.

In 2011, Vass published a study that he believed resolved the need for region-specific methodologies for postmortem interval estimation. This study, which produced a universal postmortem interval estimation formula, was based on data collected at the Forensic Anthropology Center at the University of Tennessee-Knoxville. The current study tested the Vass formula in an environment outside of Tennessee, in addition to studying longitudinal patterns of decomposition in Central Texas. A t-test was performed to test for a significant difference between the actual and expected postmortem intervals. The results of the t-test were significant for each stage of decomposition, with the largest degree of significance present in the early stage of decomposition. These results indicate that this formula is not appropriate to use at this time in Central Texas, and cannot accurately be described as a universal postmortem interval formula at this time.

Much of the discrepancy between the actual and estimated postmortem intervals can most likely be attributed to the variance in temperature and humidity between Texas and Tennessee, as Texas experiences greater periods of drought and less annual rainfall than Tennessee. A correction of the constants used in the postmortem interval formula with Texas climate data did alleviate much of the variance found in the study, however the t-test results did continue to indicate significant differences in both the early and mummification stage of decomposition.

Based on the results of this study, there is reason to believe that the Vass formula could be modified to work in new environments. The question still remains, however, of what an appropriate error range should be when dealing with matters of human decomposition. Additionally, the Scientific Working Group for Forensic Anthropology (SWGANTH) discourages PMI methods that provide overly precise calculations, which the Vass (2011) method does at this point. The Vass formula provides a point estimate, without any margin of error or range, and this is something that could drastically help with the application of the formula.

There is much work that should be done on this topic, and is actively encouraged by SWGANTH, including the incorporation of other variables like age, trauma, relative body size, the presence of clothing, scavenging activity, and different environmental conditions (SWGANTH 2013). These variables are known to affect the PMI, but the extent to which these variables affect the PMI is unknown. Another potential confounding variable is the potential for a body to be discovered at a secondary disposal site, at which point the environmental considerations that are taken into account will actually discourage an accurate PMI estimation. There are countless unknown factors to take into consideration when estimating the PMI, and before a true universal postmortem interval formula can be presented, we must gain a greater understanding of the decomposition process.

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