U.S. Department of Justice
Office of Justice Programs
National Institute of Justice

Project Narrative
Research and Development in Forensic Science for Criminal Justice Purposes

NIJ-2015-3985 - SL001149

Project Title: **Expanding on Total Body Score with Use of Geographic Information Systems (GIS)**

Submission date: April 8, 2015

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ABSTRACT

The quantification of human decomposition is a difficult issue within forensic anthropology. However, many attempts have been made to both standardize and score decomposition with the intent of estimating a post-mortem interval (PMI) with known error ranges (for example, Megyesi et al., 2005). Yet, the Megyesi et al. method (2005), aka the total body score (TBS), has several limitations. First, many regions of the body are grouped together and scored as one unit, which diminishes the fidelity in recording the often asymmetric and highly variable decomposition processes. Second, the method does not address how to handle scavenged remains, which greatly accelerates decomposition processes. Third, the method was developed from photographs with a combination of known and estimated PMIs, thus introducing unnecessary statistical noise. The proposed research will enhance the quantification of variability in decomposition by breaking down the body into 16 discrete regions, with limb antimeres scored separately.

Ten individuals will be placed in the same environment at the same time at the Anthropological Research Facility (ARF) at the University of Tennessee. Separate trials will be conducted in different seasons to capture the variability of decomposition in different seasons. A modified trait list will be developed to record the presence or absence of discrete traits in the field that are later tied to a quasi-continuous weighted scoring system to minimize bias while collecting data. Two independent observers will score the same subjects each day. The associated scores will be input into a digitized homunculus into a geographic information system (GIS), ArcGIS (ESRI, 2011), each day for each individual in the study sample. At the end of each trial, the scores for each individual will be summed for each region of the body to create a heat map that will show individual regional variability in decomposition process. Further, the scores for each of the subjects in each trail will be summed upon collection and a heat map generated to show the overarching trends in decomposition. Hot spot analysis will then be performed on the combined heat maps to identify statistically significant hot (first to decompose) and cold (last to decompose) spots. Linear regression models will be created to estimate PMI. The created models will then be validated on various holdout specimens at the ARF. The proposed research will provide more precise PMI estimates and associated error ranges by capturing greater variability in the decomposition process.

PROJECT NARRATIVE

Purpose

New forensic anthropology methods in postmortem interval estimation must meet Daubert standards (*Daubert v Merrell Dow,* 1993) of scientific reliability and the suggestions of the National Research Council's report on strengthening forensic sciences in the United States (2009). Additionally, SWGANTH (2013) have released guidelines on taphonomic observations in the postmortem interval pointing out "the identification and correct interpretation of taphonomic alterations can assist with the reconstruction of postmortem events and the estimation of the postmortem interval" (SWGANTH 2013, p. 1). However, these aforementioned guidelines do not explicitly aid the investigator in recording observations or assigning decomposition stages and consequently offers no direction on estimating the postmortem interval (PMI).

While there have been advances in attempts to quantify human decomposition (Galloway et al., 1989; Megyesi et al., 2005), none have taken a purely quantifiable approach from multiple specimens in the same conditions to document variability and hence, establish error rates. Based in part on previously funded research at UT and across human decomposition facilities, the goal of the proposed project is to simplify and standardize decomposition observations to maximize agreement among observers and reduce bias. The standardization of decomposition observations will be accomplished through the development of a list of easily identified traits that are recorded as present or absent and will rely primarily on the trait lists of Megyesi et al. (2005) as well as observations gained from a proof-of-concept pilot study. Further, heat maps will be generated for each donor within the sample to visualize the variation inherent in human decomposition, as well as to examine overarching trends in decomposition. The Megyesi et al. (2005) trait list is comprised of quasi-continuous observations that are assigned scores based on decomposition stage. Observations scores are tallied for the head/neck, trunk, and limbs and then summed together to provide a total body score (TBS). Through Megyesi and colleagues (2005) research, they have provided an equation that will allow a researcher to plug in the collected total body scores to estimate accumulated degree-days (ADD) and thus the post-mortem interval (PMI). However, the nebulous grouping of body regions limits the variability that can be observed throughout the complex process of decomposition.

The proposed research breaks the observations into 16 regions of the body, with each side scored separately. The 16 regions include the head/neck, chest, abdomen, genitals, and the left and right sides of the upper arms, lower arms, hands, upper legs, lower legs, and feet. Each region is scored independently to better capture intra-individual decomposition variation. Basic observation lists of discrete traits will be available for each region of the body, which are then assigned quasi-continuous ordinal scores, in accordance with Megyesi et al. (2005) and with observations gained through a pilot study described below. Individual region scores are summed to create a modified total body score to compare the variation in decomposition processes across individuals, as well as summed to establish the overarching trends in decomposition. Further, additional observations will be included to more holistically capture decomposition such as scavenging and the relative locations of color change. Lastly, the daily-modified TBS scores will be input into ArcGIS (ESRI, 2011) for each individual and body region. This way, at the end of the trial periods, heat maps can be created to visualize the pattern and variation among individual donors, as well as summed to visualize overarching decomposition patterns. Furthermore, the heat maps, both individual and combined will be subjected to a hot spot analysis within ArcGIS to identify statistically significant hot and cold spots. A main advantage of using a discrete trait list without the associated scores is that it limits the individual bias of the observer through removing any qualitative judgment concerning decomposition. Moreover, the proposed methodology will become more transferable and can be adopted across human decomposition facilities as well as for research involving nonhuman models at other institutions.

Goals and Objectives

The primary goal of the proposed project is to develop a modified total body score system that accounts for information from several regions of the body independently. Incorporating multiple regions of the body will create a cohesive model to more accurately estimate PMI with known error rates. Additionally, the individual regions scored on the body will allow for the creation of heat maps to visualize the specific and general trends in human decomposition, which can then be subjected to hot spot analysis to test the significance of the identified variation. One key difference in the error rates associated with the proposed research and those presented by Megyesi et al. (2005) is that the latter error rates were calculated by doubling the standard error to approximate a 95% confidence interval. Because the proposed research represents a closed population of individuals with known PMI, actual variability can be directly measured to more realistically construct error rates. The proposed project will address the following objectives: 1) modify and add observations to the Megyesi et al. (2005) TBS to create list of discrete observations for each region of the body, henceforth referred to as modified TBS; 2) determine baseline variability in decomposition using replicate human donors placed in the same environmental conditions at the same time through the heat maps and hot spot analyses within GIS; 3) create PMI models using ADD with the modified TBS, in accordance with the analytical procedures outline in Megyesi et al. (2005); and 4) validate the model on a holdout sample.

The first objective will be accomplished by having multiple researchers independently apply the new modified decomposition scoring procedure at regular intervals. Photographs will be taken each day. At the end of each trial, each researcher will score the photographs without consulting their scores from the actual observation so that scores gleaned from actual observations and photographs can be compared to test if there are significant differences in scores based on actual observation and observation of photographs. The second objective will be accomplished by entering the score data for each region into ArcGIS and generating heat maps for each individual as well as a compilation of all individuals. These heat maps will then be subjected to a hot spot analysis to determine significant regions of hot (greater decomposition) and cold (little or no decomposition) spots through time. The third objective will be completed by collecting ADD and modified TBS for each day to perform a linear regression following the analytical procedures outline by Megyesi et al. (2005) to create a new, modified TBS system with appropriate error rates. The fourth objective will be completed by applying the new procedures and models to a holdout sample to test the models predicted values on donors not included in the study area or model development. Validating the model ensures that it is applicable applicable to other seasons and environments. The main goal of the proposed research is develop the scoring infrastructure and analytical procedures that can then be applied easily in the field by forensic anthropologists, law enforcement, and medicolegal investigators.

Review of Relevant Literature

Efremov (1940) has been credited for first coining the term "taphonomy", which he described as "the science of the laws of embedding" (p. 93). However, research on decomposition started much earlier with Weigelt (1927) observing the decay of vertebrates in Texas where he noted the importance of insects in the decomposition process. Taphonomic research was then expanded by the work of paleoecologists and paleontologists, particularly, Behrensmeyer (1978) who developed a system of stages for the weathering of bone.

However, the systematic study of human decomposition rates in relation to the PMI did not emerge until Dr. William M. Bass established the Anthropology Research Facility (ARF) to study human decomposition (Bass, 1997). Since Bass founded the ARF, much research has been conducted on various aspects of the decomposition process. Mostly, decomposition research has focused on the recognition of four or five general stages of decay (Reed, 1958; Payne, 1965; Galloway, 1989; Anderson and Van Laerhoven, 1996; Marks et al., 2009; Bass, 1997). For instance, Marks et al. (2009) used human donors at the ARF to define five decomposition stages as: 1) fresh; 2) discoloration, or putrefaction; 3) bloat; 4) skeletonization; and 5) skeletal decay. It has been ubiquitously agreed upon that the localized deposition environment, specifically temperature and insects, are the most important variables contributing to decomposition rates (Mann et al., 1990; Haglund, 1997; Sorg et al., 1998; Synstelien, 2009; Reeves, 2009; Rodriguez and Bass, 1983, 1985; Parmenter and MacMahon, 2009; Rippley et al., 2012; Vass et al., 2002). Essentially, warm environments more conducive to both insect and scavenger activity will accelerate the rate of decomposition. Thus, incorporating both temperature and time in the form of ADD is necessary to estimate the PMI (Vass et al., 2002; Megyesi et al., 2005).

Megyesi et al. (2005) have developed a point-based system of observations on five regions of the body to assess the decomposition process. The points are then summed to provide a total body score, or TBS. The TBS is then related to accumulated degree-days to create a model for predicting the PMI. In fact, Megyesi and colleagues (2005) found that ADD accounts for 80% of variability in TBS. Presumably, scoring each body region independently will aid in accounting for the remaining variability in human decomposition rates. However, there are problems with this method. First, the method developed by Megyesi et al. (2005) was constructed from scene photographs where exact PMI was not always known and was sometimes estimated by an entomologist. Second, the original TBS model does not account for scavenging activity, which can greatly affect decomposition patterns (Klippel and Synstelien, 2007; Synstelien, 2009). Third, the error rates associated with the Megyesi et al. (2005) method are based on doubling the standard deviation from the observed study sample, which is not statistically ideal. Finally, the "regional" body scoring technique was likely too minimalistic in that it did not capture differential variation between arms and legs or right and left sides.

This study improves on the deficiencies of the Megyesi TBS method in that it uses empirical longitudinal data from donors with known PMI rather than photographs that had no temporal or contextual control. By placing multiple donors at the same time in the same environment, direct observation of variation within and among individuals will provide a more realistic and nuanced error rate. In addition, field and photographic observations will be compared to examine if scoring decomposition from photographs offers the same fidelity as scoring in the field. Moreover, the inclusion of a discrete list to score each of the 16 regions of the body will minimize bias in scoring inherent in the bilateral asymmetry in normal decomposition processes. In the Megyesi et al. (2005) scoring procedure, multiple traits are often listed under each observation. For example, in the limb scoring procedure, one of the observations scored consists of, "Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities". This example shows multiple observations within a single trait, which may lead to confusion among observers and thus low agreement. Compiling a list of discrete traits that can be scored in the field as either a presence or absence of that trait can then be converted to an associated weighted score that will ideally reduce bias and increase observer agreement. Further, Megyesi et al. (2005) do not address the issues of scavenging as it relates to decomposition. The addition of a scavenging observation will allow for the variation in decomposition to be more critically evaluated. Finally, the inclusion of GIS techniques will allow for both the visualization and quantification of decomposition patterns through time with the use of heat maps and hot spot analysis.

Pilot Study

As a proof-of-concept, the PI ([redacted]) carried out a pilot study in 2014-15 of five donors that were being used as part of a currently funded NIJ project on decomposition (Steadman et al., 2013-DN-BX-K037). Four researchers scored decomposition using a list of observations derived from Megyesi et al. (2005) without their associated scores and noted which stage of decomposition they believed the body to have been in (fresh, early decomposition, advanced decomposition, and skeletonization, ala Megyesi et al., 2005) and mark the observations that led them to that categorization. Additional observations that influenced each observer's classification were also noted. The initial research revealed that a larger number of variables are more useful at quantifying decomposition than that provided by Megyesi et al. 2005. In addition to a greater number of variables, converting the Megyesi et al. (2005) observations, which are mostly composites of multiple traits, into a list of discrete traits reduced inter-observer error. From this research, a list of 37 discrete observations has been developed to use for the proposed research (Table 1). The expanded trait list broke down the composite observations used by Megyesi et al. (2005) into discrete traits that can be marked as either presence or absence in practice instead of combining multiple traits into one observation. Further, observations concerning the relative quantity and activity of maggots and scavenging were shown to influence the original observer's classification. In the modified scoring procedure, each question is phrased in a way to warrant a binary response to a discrete observation. In the field, these traits would all be judged for their presence or absence and the associated scores would be tabulated after data collection as to not bias the observer. The associated observation scores in Table 1 reflect the progression of decomposition through time based on when the observations were noted from each researcher. In this sense, the associated scores were heuristically assigned based on the progression of decomposition as judged by the initial four observers. For comparative purposes, the scoring procedures of Megyesi et al. (2005) are shown in Table 2.

The pilot study period lasted 46 days between December 2, 2014 and January 14, 2015 and included nine observation events, all scored by PI [redacted]. The observations were recorded in the field on forms that only provided the list of discrete traits and a box to mark if these traits were present or absent. The data was then transcribed into the spreadsheet that converted the binary responses to their corresponding score (shown as "Associated Score" in Table 1), which were the heuristically assigned weights for each observation. The assigned weights for each score were based on deconstructed composite observations from Megyesi et al. (2005) and the sequence in which they were noted in the initial research. The regions were then summed to create a modified TBS. A homunculus was created in ArcGIS with each region being treated separately. Each region was assigned a value that corresponded to the modified TBS score for that observation period. This was completed upon each day data was collected. The individual homunculi were then added together for each donor independently to create a visual heat map that showed the different rates of decomposition for different regions (Figure 1). All homunculi for the study period were then summed to produce a more general heat map showing overarching trends in decomposition in this study sample (Figure 2). For the pilot study, hot spot analysis was not conducted given the small sample sizes. However, the general trends do show patterns relevant to decomposition progression in East Tennessee.

Table 1. Example of observation trait list with associated scores. Scores are deliberately placed in non-sequential order to minimize bias. The same observations were used for each of the 16 regions of the body with the addition of two extra observations for the head/neck (hair on scalp has slipped revealing a hair mat= 4 and Insects around mouth and/or ears = 2).

Upper Arm	Associated Score
Bloating	
Observation	
Active bloating (full bloat)	4
Partial deflation of bloat	5
Beginning Bloat	3
No bloating	1
Visible partial bloating	2

Deflation of bloat	6
Skin Coloration	
Observation	
Mottling (Pinkish, bluish, greenish) on most of limb	3
Mottling (Pinkish, bluish, greenish) Veins coloring on proximal third of limb	1
Mottling (Pinkish, bluish, greenish) Veins coloring on distal third of limb	1
Darkened skin (deep green or black) on proximal third of limb	4
Darkened skin (deep green or black) on distal third of limb	4
Darkened skin (deep green or black) on most of limb	9
Skin Appearance	
Observation	
Only dry skin, bones, cartilage remain	20
Skin is taut	1
Skin appears glossy	2
Skin sloughing off in a few areas	2
Evidence of scavenging (unnatural openings, missing elements)	3
Skin is dry	7
Most soft tissues are gone, but some flesh remains	8
Skin sloughing off in large areas	4
Adipocere formation	5
Some bone is showing	6
Skin has collapsed around bones and outline of bones is visible	6
Skin appears dark and moist	6
Purge	
Observation	
Liquefaction beginning - purge fluids seeping into soils	2

Element sitting in pool of purge fluid (soil saturated)	4
Liquefaction apparent - purge fluids leaking out	3
Insect Activity	
Observation	
Little foam at insect feeding sites	2
A lot of foam at insect feeding sites	3
Maggots very active (lots of movement)	4
Beetles present	7
Ants and flies dominate	3
Large number of maggots (~ >50% of region covered)	5
Maggots sluggish/lethargic (present but not much movement)	6
Some maggots present (~10-50% of region covered)	4
Eggs present?	1
Few or no maggots (~ < 10% of region covered)	2

Table 2. Observations and associated scores from Megyesi et al. (2005).

Observation	Score
Limbs	
Fresh, no discoloration.	1
Pink-white appearance with skin slippage of hands and/or feet.	2
Gray to green discoloration; marbling; some flesh still relatively fresh.	3
Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities.	4
Brown to black discoloration, skin having a leathery appearance.	5
Moist decomposition with bone exposure less than one half that of the area being scored.	6
Mummification with bone exposure of less than one half that of the area being scored	7
Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining.	8

Bones largely dry, but retaining some grease.	9
Dry bone.	10
Head and Neck	
Fresh, no discoloration	1
Pink-white appearance with skin slippage and some hair loss	2
Gray to green discoloration: some flesh still relatively fresh	3
Discoloration and/or brownish shades particularly at edges, drying of nose, ears and lips	4
Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present	5
Brown to black discoloration of flesh	6
Caving in of the flesh and tissues of eyes and throat	7
Moist decomposition with some bone exposure less than one half that of the area being scored	8
Mummification with bone exposure less than one half that of the area being scored	9
Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue	10
Bone exposure of more than half of the area being scored with desiccated or mummified tissue	11
Bones largely dry, but retaining some grease	12
Dry bone	13
Trunk	
Fresh, no discoloration	1
Pink-white appearance with skin slippage and marbling present	2
Gray to green discoloration: some flesh relatively fresh	3
Bloating with green discoloration and purging of decompositional fluids	4
Postbloating following release of the abdominal gases, with discoloration changing from green to black	5
Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity	6

Moist decomposition with bone exposure less than one half that of the area being scored	7
Mummification with bone exposure of less than one half that of the area being scored	8
Bones with decomposed tissue, sometimes with body fluids and grease still present	9
Bones with desiccated or mummified tissue covering less than one half of the area being scored	10
Bones largely dry, but retaining some grease	11
Dry bone	12

The individual heat maps (Figure 1) and the combined heat map (Figure 2) show both the variability in the progression of decomposition in different anatomical regions and also general trends. In East Tennessee, the head/neck and genitals region decompose faster than the rest of the body. Conversely, the limb regions are highly variable in their decomposition rate. Over the course of the study period it was noted that once scavengers had exposed muscle tissue on a limb, that particular region was continually exploited by both scavengers and insects while regions still protected by skin were ignored. This observation is especially problematic in applying the Megyesi et al. (2005) scoring procedures. If one of the limbs is completely skeletonized and the others are in various stages of decay, how should they be scored? Also, Megyesi et al. (2005) have stated that bloating is not present in the limbs, however, in our experience, bloating is observed in the limbs. The bloating in the limbs was noted due to the way in which donors are tracked in the field – ID tags are affixed to a donor's arm and leg before placement with a zip tie. The zip tie is firmly affixed compressing a region of the arm and leg and bloating can be noted.

A plot of modified TBS through time is shown in Figure 3. The preliminary results indicate that there is a semi-linear relationship through time with the modified TBS score. However, the model created by this data suffers from a small sample size and about a two-week span when data was not recorded. While it is possible to create a formula to estimate ADD from the data, the error ranges would be too large to make any meaningful conclusions and as such have not been included. Still, the concept is viable with the inclusion of larger sample sizes and further considerations on trait scoring gleaned through the pilot study.

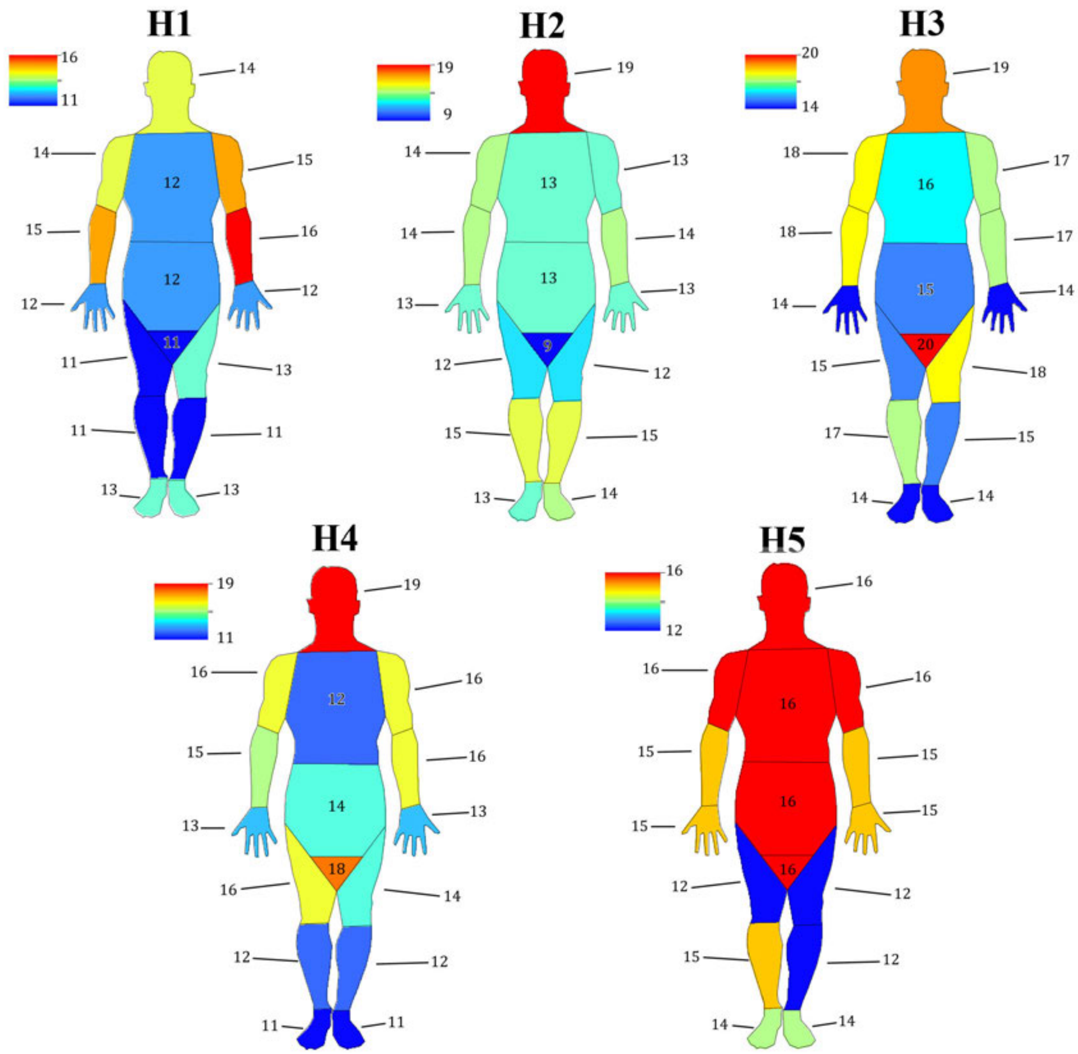

Figure 1. Heat maps for individual donors based on 46 days of decomposition. Hot spots in warmer colors (gradients towards red) decompose quicker than cooler spots (gradients towards blue).

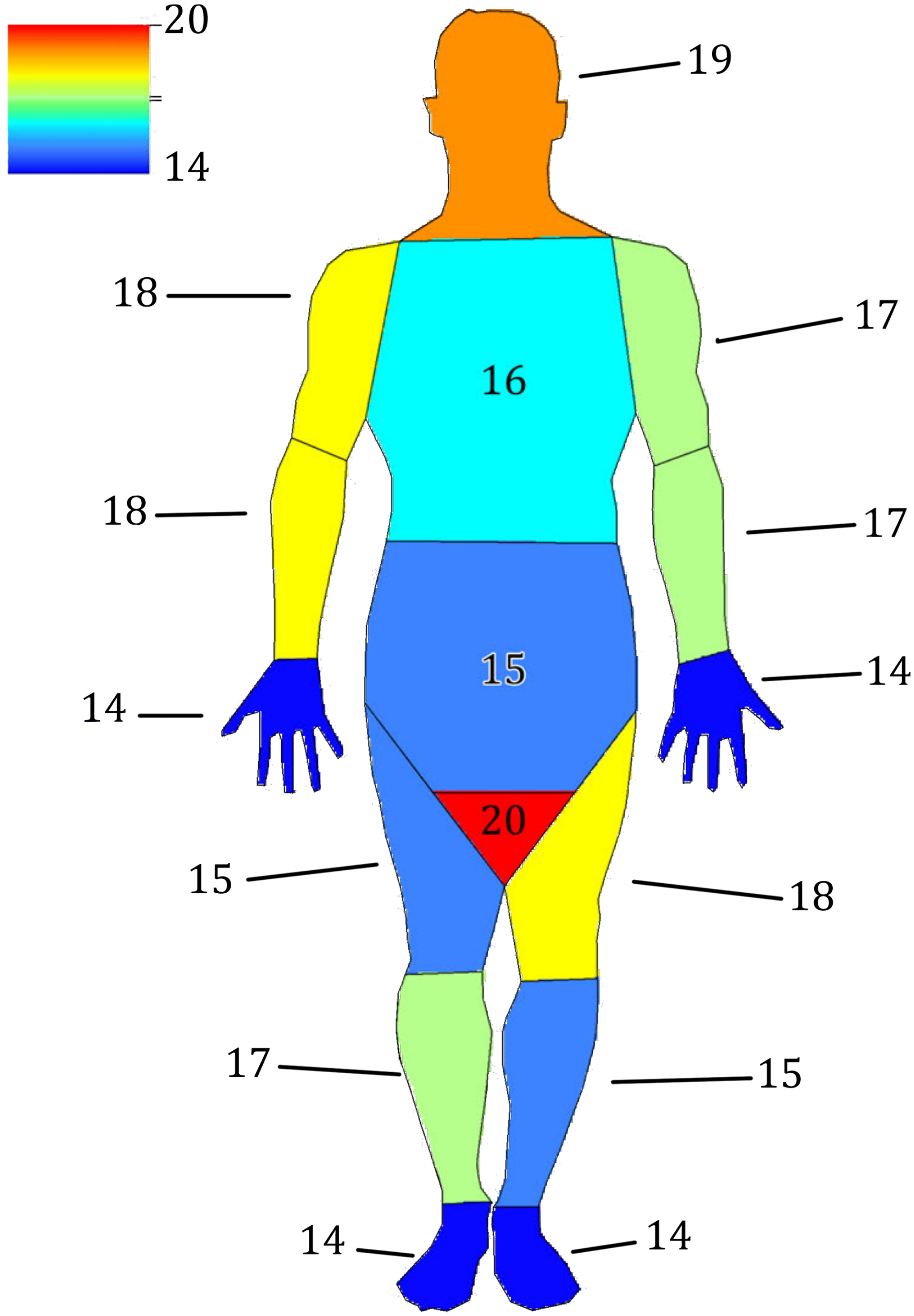

Figure 2. Heat map showing decomposition in one individual over the pilot study duration. Cooler colors (blues/greens) show the more slowly decomposing regions, while hotter colors (yellows/reds) show the regions that decompose more quickly.

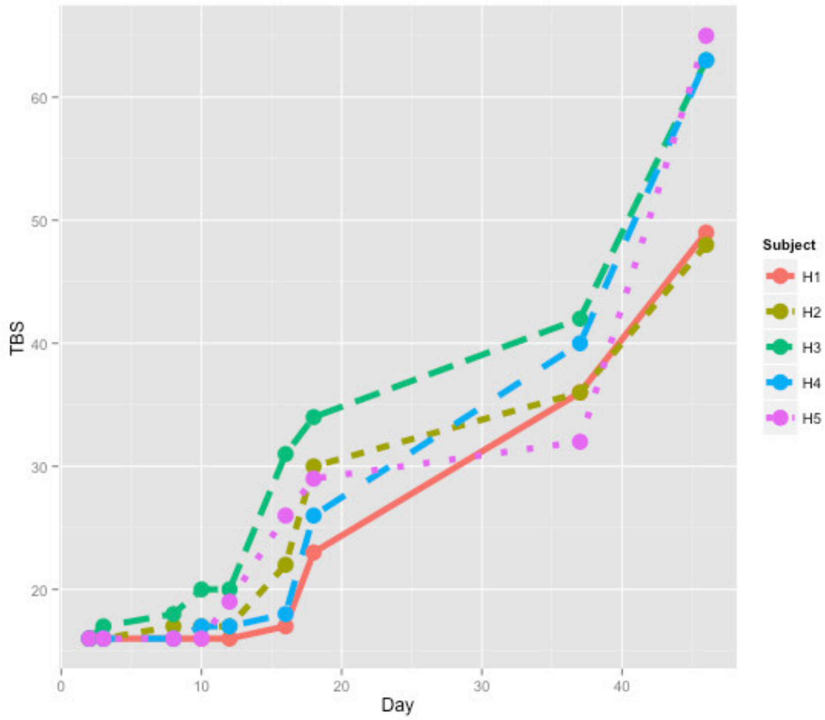

Figure 3. Plot of modified TBS over time for each subject.

The completion of the pilot study elucidated several important considerations for the proposed research. First, the addition of scoring individual, discrete traits, without any weight associated with it during collection allows for less bias, especially from practitioners that do not have much experience with decomposition. This is especially important because there are no instructions on which part of the composite observations in Megyesi et al. (2005) should be given more weight. For example, the observation "brown to black discoloration, skin having a leathery appearance" has an associated score of 5. Will this score still be a 5 if the skin is leathery without the associated color change or vice versa? Second, scavenging activity greatly accelerates decomposition around the scavenged region. Further, more precise observations are necessary. It was noted in the pilot study that the proximal and distal aspects of a particular region went through color changes before the rest of the region did. Adding in observations such as "color changes in distal aspect" or "color changes in proximal aspect" will aid in capturing more variability in limb decomposition, especially in earlier stages. Lastly, to gain a better understanding of the normal variation in decomposition rates, a larger sample is paramount. Further, a larger sample will allow for creating season specific models, as well as a more general model to predict ADD from the modified TBS scores.

Research Design and Methods

The proposed research will be divided into three components: 1) development of a trait list to examine baseline variability in decomposition using donors placed in the same environment over the same amount of time comparing photographic and field observations; 2) create a model based on modified TBS scores and ADD; and 3) validate the model on a known holdout sample. The majority of Research Component 1 will focus on fleshing out a list of observations that have high agreement and scoring multiple donors in the same settings. Research Component 1 will then establish the normal range of variation inherent in human decomposition and also elucidate overarching trends. Research Component 2 will use the data collected from Research Component 1 to develop the models for estimating PMI. Lastly, Research Component 3 will test the models on known samples as a measure of model applicability.

Description of Sample and Placement in the ARF

This project will make use of 60 human donors over the proposed two-year period. Ten donors will be placed simultaneously in six trials in the same microenvironment at the Anthropology Research Facility. A power test for generalized linear models with a large effect size and an alpha of 0.05 indicated that approximately 8 donors would be needed for each trial. A target of 10 donors for each trial will allow for wiggle room in the research design as donor procurement often fluctuates. The first trial will begin in the spring following grant approval in Year 1, then again in summer and fall. In Y2, trials will be conducted in the winter, spring, and summer leading towards the completion of the final report. Each trial will continue until the remains are skeletonized or mummified (a minimum of 2000 accumulated degree hours, or ADH).

Human donors from the Forensic Anthropology Center's (FAC) body donation program will be selected based on: 1) known time of death; 2) natural cause of death with no external trauma; 3) donor weight between 150-250 pounds; and 4) not autopsied or embalmed. To ensure that the target sample size can be achieved, donors enrolled in the study will be placed in a deep freezer to halt the decomposition process until the target sample size has been collected. Each donor will have be set in deep freeze for at least 24 hours to equalize body temperatures. Before placement, all donors will be removed from the deep freezer and allowed to thaw to ambient temperature for 24 hours before each trial begins.

All donors will be photographed and weighed upon intake at the FAC. In addition, daily photographs will be taken at placement at the ARF until the end of each trial period. All donors will be placed unclothed in the supine position at least three meters apart to ensure that microenvironment, topography, and exposure conditions are comparable, without risking a bias in insect diversity by having donors placed too closely to one another (Haskell et al., 2002; Shoenly et al., 2007). The ARF is encapsulated by a fence that keeps out large scavengers but small animals, namely raccoons, possum and mice, do scavenge donors at the ARF (Synstelien 2009; Dautartas et al., 2015). Scavenging is a necessary consideration when evaluating decomposition rates so the donors will not be placed in cages. To negate loss of small bones, the hands and feet will be bagged in mesh.

Temperature data will be recorded for each day from data loggers placed at each body and also from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). NCDC data is used as it is the type of data available to law enforcement and forensic practitioners in a real-world setting. However, many studies that use total body score also use data loggers to examine the influence of the microenvironment immediately surrounding the body to get finer grained temperature information (Steadman et al., 2013). Using both temperature data loggers and the NCDC data will allow us to examine if NCDC data is an appropriate analogue. Following Megyesi et al. (2005), average daily temperatures will be used to calculate ADD. Also in accordance with Megyesi and colleagues (2005), all temperatures below 0° C will be scored as 0° C because freezing and sub-freezing temperatures inhibit decomposition processes (Megyesi et al., 2005). Thus, data collected for each observation event will include modified TBS for each region of the body and average temperature data for that particular day for each donor.

Objective 1. Development of Trait Lists and Observer Agreement

The observation lists will be comprised of the traits listed by Megyesi et al. (2005) augmented with observations gleaned from the pilot study (discussed above). Two independent observers, the lead PI and the graduate research assistant (GRA), will score each of the 10 bodies using the complete observation list, to be tied to the associated scoring procedure post field observation, (Table 1) for each trial and take photographs of each body region daily. At the end of each trial, the same two observers will score each body again from the daily photographs to assess the variability in score assignment from actual field observation to those gleaned from photographs. The scoring procedure is presented as a presence/absence list of discrete traits that are then entered into a spreadsheet to generate their associated weighted scores. The scores represent a quasi-continuous scale, much like those of Megyesi et al. (2005). Because of this, a Student's two tailed t-tests with Welch's correction will be used to assess corroboration between actual observation and photographic observations. Additionally, inter-observer agreement will be assessed between the two observers for both photographs and actual observations using the same t-tests.

Objective 2. Determine Baseline Variability in Human Decomposition Patterns

Each donor will be scored until only skeletonized or desiccated tissue remains. The scores for each region of the body will be input into a homunculus in ArcGIS (ESRI, 2011). The homunculus will be in a raster format (an image made of pixels) where the x and y axes of the homunculus detail the location of each region, and the z value will be the observed region score. Over the study period, individual homunculi will be created for each day and then combined to create a "heat map" that shows the progress of decomposition through time (Figure 1). Further, the individual heat maps will be compiled for each season to visualize the overarching trends in decomposition (Figure 2). This way, individual variation in decomposition can be visualized, as well as general, overarching patterns. To test the significance of the heat map, hot spot analysis will be employed. Hot spot analysis identifies the significant hot and cold areas in a given weighted feature set, which, in this instance is the weighted composite scores for each body region, using the Getis-Ord Gi statistic (ESRI, 2011). The output of hotspot analysis is a new layer showing the associated Z-scores and *p*-values projected on the homunculus. Using hot spot analysis will illustrate the statistically significant regions of decomposition, which can be evaluated for each of the different seasons to examine the significance of decomposition trends particular to each season.

Objective 3. Model Creation to Estimate PMI with ADD

Two models will be created – one for each of the independent observers' scores. The temperature data will be converted to ADD by adding the average temperatures each day. Next, the model will be created in accordance with the procedures outlined in Megyesi et al. (2005): the ADD and PMI will both be log-transformed and the modified TBS will be squared. The ADD and modified TBS will be subjected to a linear regression (direct least-squares). The nature of the data collected through the pilot study demonstrated a curvilinear relationship with the modified TBS through time so using the analytical procedures put forth by Megyesi and colleagues (2005) is applicable for the proposed research. In sum, two models will be created for each season, as well as combined to make two more general models encompassing the duration of the entire project period. The slopes of the two different models will be tested for independence with the analysis of covariance (ANCOVA). Model comparisons will add to the replicability of the modified procedures for estimating the PMI.

Objective 4. Model Validation

All created models will be tested on a holdout sample. The holdout sample will be comprised of a total of five donors who were not included in the study and who did not contribute to the model's creation. The holdout sample will make use of donor placements for a particular season as they become available. The holdout sample will be comprised of donors who meet the current study's criteria, but will be placed in different areas of the ARF. All holdout donors will be placed supine and unclothed. An R^2 and RSME will be calculated from the trained model, as well as the fitted model with the new holdout data. Assessment of model validation will be based on performance of the newly fitted data through an analysis of the residuals. Ideally, the errors of the trained and validated models will be comparable.

Management Plan and Organization

The proposed research project will be conducted by the FAC at the University of Tennessee, Department of Anthropology. The project is headed by [redacted] who will be responsible for data collection, data analysis, data interpretation and synthesis, as well as contributing to reports and data dissemination. The co-PI, [redacted] and will oversee enrollment of the donors into the research project, contribute to the data analysis and interpretation, progress reports and publications. We have developed a realistic timetable for completion of each study phase (Appendix III). The [redacted] has successfully completed eight NIJ grants since 2007 (and currently managing nine grants).

Implications for Criminal Justice Policy and Practice in the United States

Estimating time since death and decomposition events is central to forensic science and the criminal justice system in the United States. Previous research (Megyesi et al., 2005) has taken the requisite steps towards quantifying the decomposition process, though unaccounted for variability still remains. Creating a more holistic observation list that examines multiple regions of the body independently will add fidelity to the analysis and yield more accurate results. The results of our study will directly impact the medicolegal community by more precisely estimating the PMI, accounting for more sources of error (differential decomposition of paired elements, for example), and produce known error rates. The legal value of the PMI is increased when there are associated, quantifiable error rates (Christensen and Crowder 2009, Christensen 2004). Further, the associated error rates, which are based on scientifically-derived data, will allow for the modified TBS to be *Daubert* compliant (*Daubert v Merrell Dow,* 1993).

The proposed research will provide a standardized data collection protocol that includes trait observations in layman's terms. The straightforward observation list will be accessible to all practitioners regardless of experience or education level in evaluating decomposition. This is especially important because the observed changes in human decomposition are highly qualitative and subjective. As learned from the pilot research, it was shown that the two observers (one familiar with decomposition and the other not) often relied upon different stimuli to judge decomposition. For example, the observer who had no prior familiarity to scoring decomposition heavily weighted the smell to dictate stage assignment, while those with more experience relied upon physical characteristics, such as skin slippage. Simply scoring the presence or absence of discrete traits will remove any bias because the observer does not make any conclusion about the stage of decomposition – they simply score what is observed. The trait lists and associated scoring system will be made available to the law enforcement and scientific communities along with all of the observed longitudinal data to promote further testing in different geographic regions. To meet the demands of the medicolegal community, longitudinal studies of human decomposition in different geographic regions are paramount.

Capabilities and Competencies

The Forensic Anthropology Center was established with the mission to conduct innovative research in forensic anthropology, train students and law enforcement in forensic techniques, and demonstrate the science of forensic anthropology to the general public. The FAC is managed by a Director, an Associate Director, two Assistant Directors and 8-10 graduate student staff. The FAC oversees the body donation program, the ARF, the Bass Donated Skeletal Collection, and other skeletal collections.

Located on approximately 2.5 acres of land along a bluff overlooking the Tennessee River, the ARF is the first outdoor natural laboratory dedicated to the study of human decomposition and related subjects. Scores of researchers have conducted scientific studies at the ARF and it serves as a training site of more than 200 students and law enforcement personnel per year. Over 3000 individuals have pre-registered to donate their body to the program, and the William M. Bass Donated Skeletal Collection now contains more than 1300 donated skeletons.

The FAC PIs are well qualified to accomplish the objectives of this project. [redacted]. [redacted] has worked extensively in GIS and taken both basic and advanced GIS modeling courses. Further, he has used GIS as part of his Master's thesis and has taught an advanced modeling course using GIS to graduate students at [redacted] and is scheduled to teach an archaeology GIS course at the [redacted]. Additionally, he will direct the research design, conduct all statistical analyses, and develop the protocols for scoring decomposition, analyzing the data, and preparing the decomposition heat maps. [redacted] is the [redacted] and will facilitate and oversee the research at the ARF. She is a Diplomate of the American Board of Forensic Anthropology and has served as an expert witness in U.S. state and federal courts and is an international consultant. She will be responsible for data management, data analysis, and writing and submitting semi-annual reports to OJP. [redacted] has previously been a PI for National Science Foundation (NSF) and Wenner-Gren Foundation grants and is currently a PI or co-PI on two NIJ grants.

Outcomes, Evaluation, Dissemination Strategy and Future Directions

Outcomes and Evaluation

This study will have a significant impact on the field in that it will provide a simple scoring system to adequately encapsulate the decomposition process in multiple regions of the body, examine the normal variation in decomposition, and provide PMI estimates with associated error rates. The result of the study will provide comprehensive and validated PMI estimates for criminal justice purposes. Further, this study will include additional quantitative measures of decomposition to provide more objective approaches to PMI research. The broader impact of our project contributes to the efforts to quantify forensic data that have historically been subjective in nature. Our principal outcome will be a quantitative expansion of the commonly used TBS system developed by Megyesi and colleagues (2005). This will include visualizations of the normal variation inherent in decomposition.

Dissemination Strategy

The target audience for the proposed research includes forensic science researchers and practitioners, law enforcement, and anthropologists who conduct or apply time since death research and testify in court. Law enforcement agencies, forensic pathologists and criminal attorneys will be directly impacted by this research as time since death estimations are essential for identification and investigative purposes.

Given the far-reaching significance of this research, the results will be disseminated in journals representing forensic science and anthropology. Specifically, abstracts will be prepared for the 2017 annual American Academy of Forensic Science meetings. Further, manuscripts will be prepared for submission to the *Journal of Forensic Sciences*, *Forensic Science International,* and the *International Journal of Legal Medicine.*

Forensic professionals, including federal, state, and local law enforcement agents and medicolegal investigators nationwide frequently attend the forensic short courses offered by the FAC. Each summer we offer a minimum of five courses that serve over 100 professionals and pre-professionals in the medicolegal community. Course participants come from agencies and universities throughout the United States and internationally. The PI and co-PI are [redacted] faculty members able to disseminate these results through the short course curriculum. Further, we provide agency-specific training (e.g. to FBI Emergency Response Teams) in which our research figures prominently in their training. In the event of funding, the FAC will offer a condensed short course (2-3 days) for law enforcement to teach the protocols and analytical procedures for using the revised method. In addition to adult education, the PIs are committed to youth outreach. The FAC employs our research as a means to teach STEM to youth as we provide an average of 30 presentations on forensic anthropology and forensic science per year to school age children around the country.

Future Directions

This project will provide the necessary baseline data and infrastructure for standardizing decomposition observations in an easy-to-use format. This research can then be applied to other facilities capable of human decomposition research to examine the variability in different geographic locales. The provided infrastructure will thus allow for further researchers to create regional specific PMI estimation equations for broader applicability. Additionally, broadening the geographic breadth will aid in the identification of observations that are location specific due to differing environmental conditions. Lastly, additional geospatial analyses could be incorporated easily through GIS. For example, space-time cluster analysis could be used to examine the influence of decomposition patterns given the temporal differences. This way, the differences in decomposition processes can be analyzed seasonally to investigate significant differences among temporal units. Alternatively, ADD could be used as the unit in the space-time cluster analysis to examine the differences in ADD units through time.

APPENDIX I. REFERENCES

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APPENDIX II. PROPOSED PROJECT TIMELINE AND EXPECTED MILESTONES

Year 1 (January 1 - December 31, 2016)

Month	Grant Activity
January 1 to June 30	• Develop final observation trait list • Assign GRA • Train GRA in required protocols • Place first round of 10 winter trial donors (estimated January 8) • Place first round of 10 spring trial donors (estimated March 20) • Place first found of 10 summer trial donors (estimated June 20) • Submit quarterly financial report to NIJ OJP – March 31 & June 30

July 1 to Dec. 31	• Submit semi-annual progress report to NIJ OJB - July • Place first round of 10 fall trial donors (estimated September 20) • Analyze data from Y1 trials • Submit abstract to the AAFS to present preliminary results at 2017 Annual Meetings August 1 • Submit quarterly financial report to NIJ OJP - September 30 & December 31

Year 2 (January 1 - December 31, 2017)

Month	Grant Activity
January 1 to June 30	• Place second round of 10 winter trial donors (estimated January 8) • Place second round of 10 spring trial donors (estimated March 20) • Place second round of 10 summer trial donors (estimated June 20) • Submit quarterly financial report to NIJ OJP March 30 and June 30 • Submit semi-annual progress report to NIJ OJP June 30
July 1 to September 30	• Submit semi-annual progress report to NIJ OJP July • Place second round of 10 fall trial donors (estimated September 20) • Complete all analyses • Submit abstract to AAFS to present preliminary results at 2018 Annual Meetings August 1 • Submit quarterly financial report to NIJ OJP - September 30 • Submit final technical report - September 30
October 1 to Dec. 31	• Compile all data and complete final analyses • Prepare manuscripts for submission to various journals • Upload collected data to the National Archive of Criminal Justice Data (NACJD) • Submit quarterly financial report, semi-annual progress report, and final draft of Final Technical Report to NIJ OJP