DIFFERENTIAL DECOMPOSITION OF HUMAN REMAINS IN SHALLOW BURIALS IN THE HUMID SUBTROPICAL ENVIRONMENT OF CENTRAL TEXAS

by

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1. INTRODUCTION

Buried human remains are commonly encountered in homicide and human rights investigations (Crossland 2000, Haglund et al. 2001, Sea and Beauregard 2017). According to Sea and Beauregard (2017), burial in shallow graves accounts for 21% of all homicide body disposals, which are often dug quickly and no deeper than 120cm (Whittington 2019). In many of these instances it is important to establish a postmortem interval (PMI) for the victims in order to aid in the investigation of the crime. However, commonly used methods for estimating the postmortem interval are primarily based on animal models or human remains allowed to decay on the ground surface and may not be valid for estimating PMI for buried human remains (Galloway et al. 1989; Megyesi et al. 2005).

Previous studies have shown that the decomposition rates of buried remains differ from surface remains (Buekenhout et al. 2016; Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire 1999; Wilson et al. 2006; Whittington 2019), but these studies have not proposed time-successive stages for estimating the PMI of bodies in a burial context similar to those by Galloway and colleagues (1989) or Megyesi and colleagues (2005) for surface remains. Disposal of bodies in burials can vary by depth, clothing or wrapping present, enclosure in a coffin, or other factors that can affect decomposition rates. The majority of studies on burial decomposition, independent of depth or grave type, all agree that decomposition is slower as compared to that of remains allowed to decompose on the surface (Buekenhout et al. 2016; Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire

1999; Wilson et al. 2006; Whittington 2019). Previous studies also suggest that deeper burials or burials inside coffins or other coverings decompose at a slower rate than those of shallower burials (Buekenhout et al. 2016; Rodriguez & Bass 1985). Depth of burials can effect things such as access by insects or scavengers, temperature and changes to surrounding soil and vegetation, suggesting that more shallow burials allow for more access to scavengers whereas deeper burials allow for cooler temperatures and thus slower decomposition rates (Rodriguez & Bass 1985). Therefore, not only are decomposition rates of buried remains different from surface remains, but they can also vary based on the depth and type of burial.

Furthermore, previous studies have shown that animal models may not be accurate for determining the pattern, rate, or variability of human remains (Dautartas et al. 2018). Therefore, since almost one-fourth of all disposed homicide victims are buried, it is pertinent to document the pattern, rate, and variability of decomposition for buried human remains in order to understand how the decomposition rate of buried remains differs from surface remains. This information can then be quantified for calculating the post-mortem interval in buried remains.

The purpose of this research study is to document and analyze the decomposition rates, patterns, and variability of human remains in shallow graves in central Texas and determine how they differ in the pattern and rate of decomposition from human remains decomposing in central Texas on the ground surface. This information will then be used to provide suggestions for improving forensic PMI estimates for buried human remains in central Texas. The goals of the study include: 1) determining if the pattern of decomposition in buried remains follow those used in the total body scoring method

(Megyesi et al. 2005), 2) compare the results to other studies on buried human remains (Buekenhout et al. 2016; Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire 1999; Wilson et al. 2006; Whittington 2019; Vass 2011), 3) determine if the Megyesi et al (2005) accumulated degree day calculations accurately estimate PMI for buried remains, and 4) make recommendations for modifications to the TBS scoring system and the ADD equation for calculating PMI. Data were collected specifically for this project, including temperature and total body scores, from shallow buried human remains in San Marcos, Texas. Comparative data from other locations was not used for PMI calculations since decomposition rates and appearances are variable depending on climate and season, making the reuse of data from other climates less appropriate.

2. LITERATURE REVIEW

PMI Estimation Methods

The postmortem interval refers to the time that has passed since an individual has died, and is often used in forensic homicide investigations to corroborate eyewitness testimonies, establish possible victim identifications, and verify suspects' alibies (Megyesi et al. 2005). Estimations of the PMI are often calculated based on the gross morphological features the remains exhibit at the time of discovery to establish a stage of decomposition. Galloway et al. (1989), for example, describes the different stages of decomposition and the characteristics associated with them. Using cases from the medical examiner's office in Arizona, Galloway and colleagues (1989) created a chart ranging from early decomposition to skeletonization for surface remains. They describe the first stage of decomposition as "fresh" where the body does not exhibit discoloration or insect activity. Their second stage of decomposition is "early decomposition" where the body begins discoloration, bloating and some purging of bodily gasses and fluids. The third stage Galloway and colleagues (1989) describe is "advanced decomposition," which is when the body begins to decrease in size (i.e., lose biomass) after bloating and either becomes mummified, skeletonized or adipocere formation occurs. The forth stage of decomposition is referred to as "skeletonization," which is when almost all tissue has decomposed and the bones are left exposed. They describe the fifth and final stage of decomposition as "extreme decomposition" where the bones are subjected to weathering, sun bleaching and exfoliation (Galloway et al. 1989). Galloway and colleagues (1989) state that depending on climate and environment not all remains will reach extreme decomposition or even skeletonization.

Megyesi and colleagues (2005) built on the Galloway et al. (1989) study, using similar descriptions of decomposition in accordance with above ground forensic cases but quantified the stages of decomposition into a scoring method known as the total body score (TBS). To obtain the TBS, different stages of decomposition are numerically scored for three different anatomical regions of the body. The head and neck, trunk, and limbs are scored separately using this system and then summed to get the TBS.

Megyesi and colleagues (2005) recorded the changes in the remains from early decomposition to skeletonization along with the temperature data from each day. With this temperature data, Megyesi and colleagues (2005) recorded the accumulated degree-days, or ADD, for each set of remains. ADD refers to the sum of all the average daily ambient air temperatures above 0°C since a body has started the decomposition process (Megyesi et al. 2005). They then developed a regression equation to estimate the ADD using TBS as the dependent variable. The TBS is plugged into a regression formula to calculate the estimated ADD needed for the body to reach the observed TBS. The estimated ADD can then be used in accordance with local weather to essentially count back to the possible day of death, or when decomposition started (Megyesi et al. 2005). However, this method has not been tested on shallow burials.

Recently, researchers have acknowledged a need for improved PMI calculation methods for modes of decomposition other than the standard, unclothed surface decomposition commonly studied at decomposition research facilities. Studies conducted by Bates (2014), Sears (2013), and Suckling (2011) looked at the decomposition of surface remains in Central Texas, specifically at the Forensic Anthropology Research Facility at Texas State University in San Marcos, and addressed issues with TBS and

PMI estimation methods but did not discuss buried remains. The burial of victims in shallow graves poses a problem for investigators since the rate of decomposition for buried remains is extremely variable (Buekenhout et al. 2016). Factors such as burial depth, burial position, clothed or unclothed, concealed or not, scavenger disturbances and many others can affect the rate at which buried remains decompose (Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire 1999; Wilson et al. 2006; Vass 2011).

Forensic case studies and original research projects have looked at the decomposition of buried remains, both human and non-human, and found that overall decomposition is often delayed for the buried remains (Buekenhout et al. 2016; Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire 1999; Wilson et al. 2006). According to Casper's Law the decomposition of buried remains takes 8 times longer than that of surface remains (Casper 1861; Troutman et al. 2014; Fiedler & Graw 2003), yet this was not determined through experimental data collection or comparison tests and other burial decomposition studies have found this time rate to be inconsistent (Marais-Werner et al., 2017; Carter et al. 2010, Vass 2011). Previous studies on the decomposition of buried remains have discussed that the three main aspects that affect the decomposition rates include temperature, adipocere formation and insect activity (Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire 1999; Wilson et al. 2006; Vass 2011). One study conducted by Vass (2011) examined the decomposition of human remains both on the surface and in burials ranging from 46 cm to 107 cm at the Anthropology Research Facility at the

University of Tennessee Knoxville in order to come up with improved PMI calculation formulas. While this study was able to develop a new PMI estimation for buried remains, it was conducted in a climate dissimilar to that of Central Texas and also used individuals who were clothed during burial. Furthermore, the method has not been widely tested on buried remains in Central Texas. Thus, if investigators use methods for calculating the postmortem interval that were based on data from surface remains or buried remains in a dissimilar climate the results may be inaccurate.

Factors Affecting Decomposition

Temperature/Moisture

The studies conducted by Fiedler and Graw (2003), Mann et al. (1990), Marais-Werner et al. (2017), Schotsmans et al. (2010), Schultz (2007), Simmons et al. (2010), Turner and Wiltshire (1999), Vass (2011), and Wilson et al. (2006) all discuss the role of temperature on the decomposition of buried remains. While these studies were all done in different environments with different temperatures, the majority found that the temperatures in the graves were lower than the outside temperatures. It is known that warmer temperatures accelerate the decomposition process, whereas cooler temperatures slow it (Mann et al. 1990). Marais-Werner et al. (2017) also found that the temperatures in the graves were more consistent over time than the surface temperatures. This consistency can be beneficial when calculating the PMI because it can be more applicable if the variability is decreased. Cooler temperatures, along with moisture, in the burials can also lead to the formation of adipocere, which becomes stable and slows decomposition (Rothschild et al., 1996; Schotsmans et al. 2010).

Another study conducted by Archer (2003) found that higher precipitation levels in congruence with higher temperatures increases the rate of decay and mass loss in decomposing remains. While rainfall in cooler climates or seasons can often delay decomposition, Archer (2003) found that in warmer periods when there was more rainfall remains decomposed faster and she suggests that buried remains may be subject to this as well because the soil retains much of the moisture around the remains allowing for more bacterial and maggot interaction. Yet most of these studies were conducted in climates, temperatures and seasons dissimilar to that of summer in Central of Texas, and the majority used nonhuman remains with much smaller body masses. Another difference with this study compared to others, specifically with the Megyesi et al. (2005) TBS scoring method, is that the Megyesi et al. (2005) method uses ambient air temperatures to calculate ADD and thus PMI. Air temperatures and moisture levels can often differ from that of burial temperatures and moistures levels, due to protection from solar radiation and wind and increased insulation from surrounding soil (Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner and Wiltshire 1999). According to a study done by Lennartz (2018) temperature and humidity levels can have an impact on the moisture content seen in decomposing human remains, and can effect how quickly they become desiccated. While this study was done on remains allowed to decompose on the surface, she did find that exposure to solar radiation did not have a significant impact on the moisture content of the remains, instead temperature had an inverse relationship and humidity had a direct relationship to moisture content levels therefore suggesting that the presence of moisture in burials is more correlated to temperature than protection from solar radiation.

Adipocere Formation

The next factor observed often in buried remains is adipocere formation. Adipocere refers to the development of a wax-like layer on the outside of a body, due to the hydrolysis of fats from within the body, for this fatty layer to form the environment has to be humid, anaerobic, and in most cases covered from exposure to outside elements (Forbes et al. 2004). This kind of environment prevents remains from becoming desiccated due to lack of sun and wind exposure, and allows the anaerobic bacteria to aid in the formation of adipocere. Adipocere is often considered comparable to mummification though because it preserves the body until the environment changes and decomposition continues (Ubelaker & Zarenko 2011).

Previous studies have shown that burials often create this type of environment, thus adipocere is often found on buried remains (Schotsmans et al. 2010; Forbes et al. 2004; Fiedler & Graw 2003; Vass 2011). However, the Megyesi et al. (2005) descriptions do not include adipocere formation. One example in particular from the case study done by Schotsmans et al. (2010) showed how a homicide victim, who was partially buried, formed adipocere on all aspects of the body that was buried and none on the appendage that was exposed to the surface environment, thus affecting the TBS estimations made by the investigators. This made it difficult to calculate the PMI because the exposed part of the body was desiccated, suggesting later decomposition stages, whereas the part with adipocere formation still had some of the internal organs preserved. Although adipocere does slow and in some cases temporarily halt decompositional processes when present on remains, the presence of certain bacteria in soil or exposure to air or water can lead to the degradation of adipocere and recommencement of decomposition (Ubelaker & Zarenko

2011). Adipocere is highly dependent on the environment of the grave and previous studies of adipocere have not been done in Central Texas shallow grave environments. Other studies on adipocere have also not provided a time estimation for how long it takes adipocere to form or deteriorate, making the timing of adipocere an important aspect to take into account in this thesis study as well. The study conducted by Vass (2011) was able to provide a PMI calculation formula for buried remains, yet this formula includes the assumption that there is adipocere formation since that is seen in almost all burials in climates similar to that of Tennessee. Yet, as will be discussed in the later sections, adipocere formation is not always observed in burials and can change throughout burial duration, especially among graves in a hotter climate like that of Texas.

Insect Activity

The other aspect that affects the rate of decomposition for both surface and buried remains is insect activity, which can be one of the "primary accelerants" in decomposition by their roles in the consumption of soft tissues and increasing cadaver body temperatures (Simmons et al., 2010). In studies conducted by Mann et al. (1990), Schultz (2007), and Simmons et al. (2010), these researchers found that the lack of access by insects was one of the essential factors that slowed the decomposition of buried remains. Simmons et al. (2010) focused specifically on the access of insects and how this affects decomposition rates by limiting the access of insects to rabbit remains both through burial and insect screens. They found that in both of these limited access environments the rates of decomposition were slowed dramatically, simply due to the lack of insect activity. In the study conducted by Schultz (2007) on the decomposition of buried pig remains in Florida, he found that there were no maggots or beetles present in the graves upon exhumations, yet there were “extensive ant colonies,” which they discussed could have aided in skeletonization due to the fact that ants often scavenge human tissue.

Yet burial does not always inhibit insect access and colonization. In several forensic cases discussed by Gaudry (2009), individuals were buried in shallow graves ranging from 40 to 80 cm with some wrapped in materials and others placed directly in the ground. In each of these cases several species of insect larvae and adult insects were found with the remains, allowing for PMI calculations to be estimated based on their presence. While some PMI estimations were relatively close to the actual time since death, some were less accurate due to a delayed colonization by these certain insects. This thus suggests that in shallow burials it is possible for insects to colonize and aid in the decomposition of remains (Gaudry 2009). Another study conducted by Turner and Wiltshire (1999) on the decomposition of pig remains in burials found that scavenger activity caused enough exposure of the remains for flies in the order of Diptera and other insects to colonize and thus effect decomposition rates. If there is allowed access for the colonization of insects, even if it is delayed, this can accelerate the decomposition of buried remains due to the fact that insects would be allowed to propagate without interference from predators, intense temperatures or desiccation from sun or wind (Turner & Wiltshire 1999).

Elaboration on Previous Studies

These previous studies on buried human remains do a good job of describing and analyzing the differences between buried and surface remains, and the aspects that contribute to the differences in rates and appearances of buried decomposition. Yet the burial decomposition studies conducted by Marais-Werner et al. (2017), Klein (2013), Schultz (2007), Simmons et al. (2010), Turner & Wiltshire (1999), Gaudry (2009), and Wilson et al. (2006) use non-human remains as a substitute for humans. While non-human remains are often used in decomposition studies, because of lack of availability of human remains and the size and location restraints that go along with using human remains, they are not exact indicators of how decomposition will occur in human remains (Steadman 2018). Other studies have discussed the decomposition of buried human remains, including Fiedler (2003), Forbes et al. (2004), Galloway et al. (1989), Janaway (1996), Mann et al. (1990), and Schotsmans et al. (2010), but these studies have not discussed how this can influence PMI calculations. The only study that has actually proposed a new method for calculating PMI based on buried human remains is the one conducted by Vass (2011), yet this study was done at the research facility in Tennessee, which has a much different climate from that of Texas and thus decomposition rates and patterns are dissimilar. The major difference between this research study and previous ones is that few have been conducted in a humid subtropical climate like that of Central Texas, use human remains, and use total body scores and temperature data to improve PMI estimations.

3. MATERIALS

Donations

Six donated human bodies from the Willed Body Donation program at the Forensic Anthropology Center at Texas State were used for this study (Donors 2019.026, 2019.033, 2019.036, 2019.038, 2019.042, and 2019.052). The Willed Body Donation program at Texas State "accepts body donations for scientific research purposes under the Uniform Anatomical Gift Act" (FACTS, 2019). The Uniform Anatomical Gift Act provides a "framework for the donation of organs, tissues, and other human body parts in the US" in order to standardize body donations nationwide (Martinez, 2013). All of the donors used in this study were non-autopsied and received either the day they died, or were refrigerated and received within 3 to 4 days after death. The use of non-autopsied donors was so that decomposition rates would not be affected by the autopsy incisions (Mann et al. 1990), and so that the torsos of the donors would not be filled with dirt making exhumations easier. All donors were buried in supine position and unclothed in order to prevent these factors from affecting the decomposition rates and to keep them similar to the surface remains, which are typically placed supine and unclothed as well. Clothing and fabric types have been found to cause inconsistencies in rates of decomposition (Cahoon, 1992; Fielder & Graw, 2003)(Figure 1).

Figure 1: Example of donor placement in grave immediately before placement of temperature probes and burial (Donor 2019.033)

Climate, Weather, and Soil

The climate at the Forensic Anthropology Research Facility, or FARF, located on Freeman Ranch in San Marcos, Texas is typically considered a humid sub-tropical climate, with some occasions of drought leading to a more semi-arid climate (Dixson 2000). The weather at FARF during the period each donor was buried from March 2019 to October 2019 was somewhat variable, with average monthly temperatures ranging from the highest at approximately 38 degrees Celsius in August and the lowest at 0.56 degrees Celsius in October (Figure 2). Precipitation levels were the highest during April and May and the lowest in March and July, with many days of intense sun as well (Figure 3). Above ground average temperatures and precipitation level data were collected from U.S. Climate Data (2020) for San Marcos, Texas. Temperature data were also collected for ADD calculations from both loggers within the graves and from above ground temperature data from a local weather station at Freeman Ranch. According to Carson (2000), the soil type at FARF is considered a mixture of both rumple and comfort soils.

These types of soils are usually well draining and have a low capacity for water storage (Forbes et al., 2004). According to the soil survey map provided by the USDA's soil survey website (Soil Survey Staff 2020) this specific area of FARF falls mainly in the rumple category of soil. The typical traits of this soil type include "gravelly clay loam" soil from the surface to about 25 cm, then "gravelly or cobbly clay" from 25 cm to about 71 cm and then bedrock usually after about 72 cm, with typically low salinity levels and water storage capacity (Soil Survey Staff 2020). This is congruent with what was seen during the digging of graves for this study because bedrock or very large, immovable rocks were reached at around 70 to 75 cm.

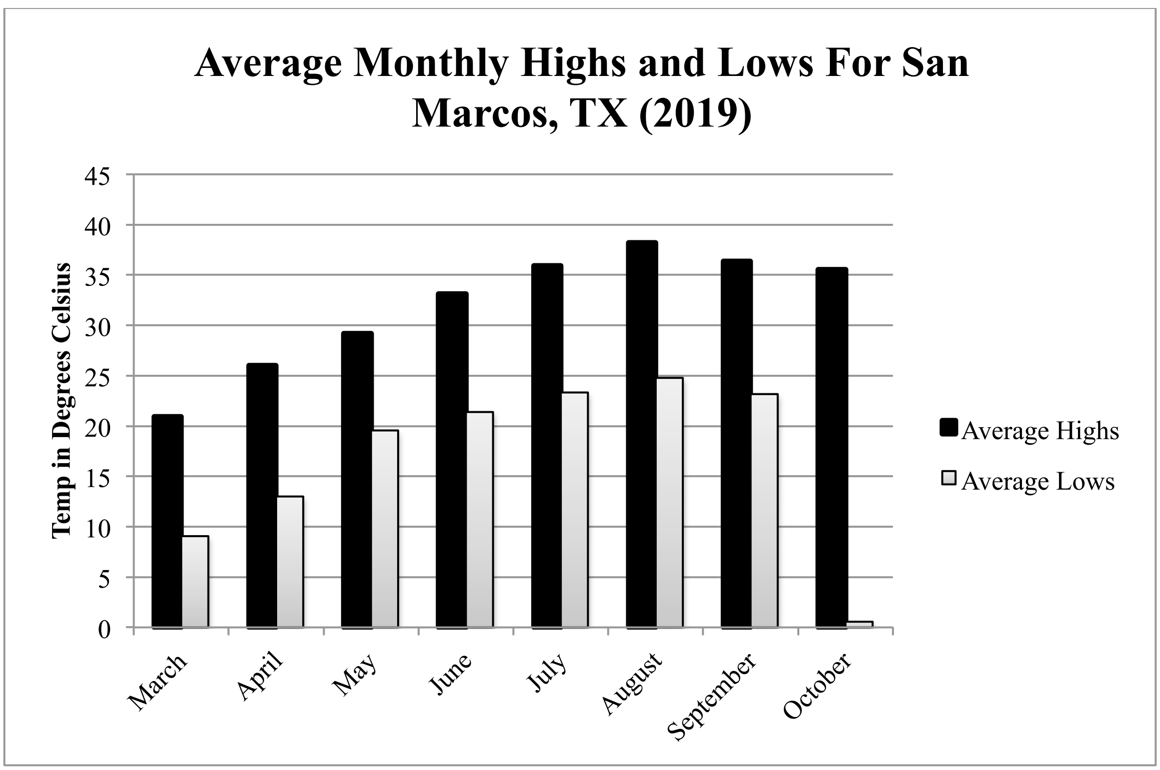


Figure 2: Monthly average highs and lows in degrees Celsius for San Marcos, Texas from March 2019 to October 2019 (US Climate Data 2020).

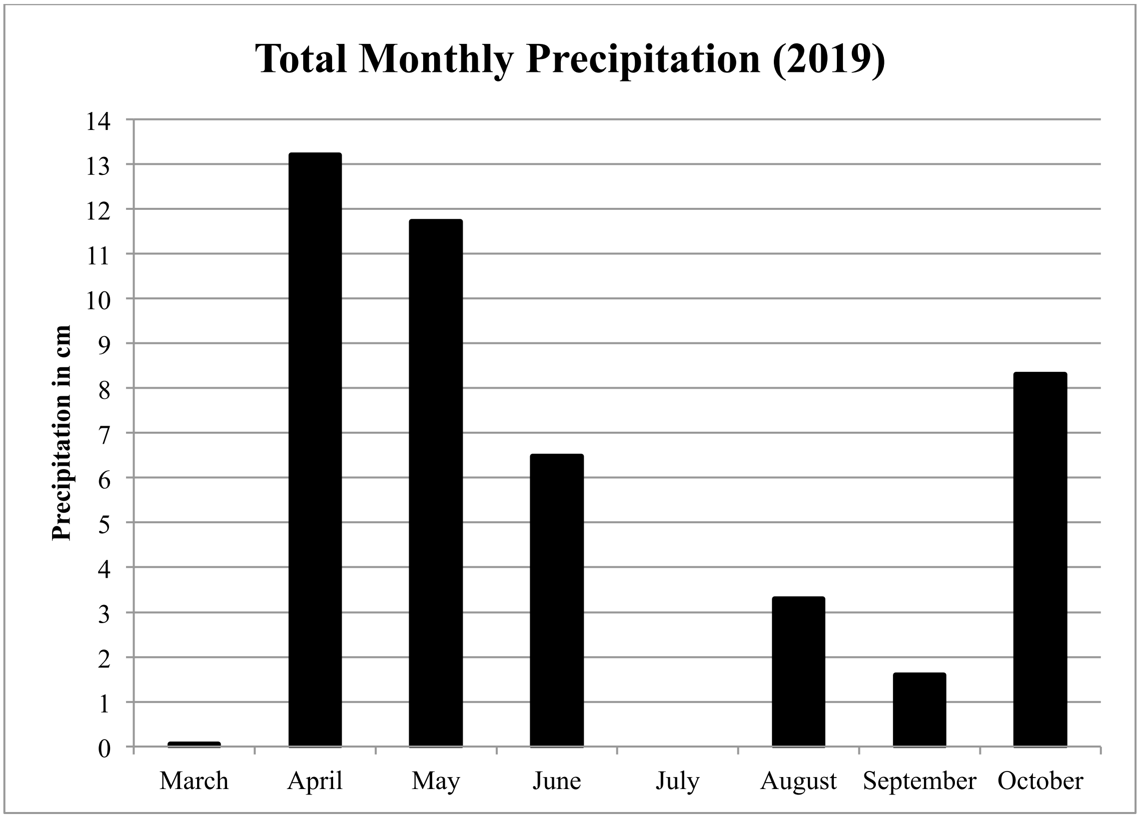


Figure 3. Total accumulated precipitation levels in cm for each month from March 2019 to October 2019 in San Marcos, Texas (US Climate Data 2020).

4. METHODS

Burial/Exhumation

The graves were dug on March 14th, 2019 with the use of a skid-steer loader to remove the majority of dirt and provide a rough outline, after which shovels were used to clean out to the remaining dirt and make the graves more uniform in depth and shape. Since this study is more focused on forensic application and not archaeological or traditional burial contexts, the graves were dug to be shallow (Morton et al. 2015; Sea and Beauregard 2017). For consistency in depth and soil type, each grave was dug side by side and measured in the center with the use of a tape measure and line level to ensure a depth of between 70 and 75 cm, which is approximately the average depth used in other burial decomposition studies (Marais-Werner et al., 2017; Klein, 2013; Schultz, 2007; Simmons et al., 2010; Turner & Wiltshire, 1999; Wilson et al., 2006) (Table 1). Once the donors were placed in the graves, one temperature probe was placed under the body and one was placed inside the torso. These loggers were built by Thomas Chappell from Texas A&M University and were powered by the use of solar panel. Temperature was collected every 10 minutes from the time of placement till exhumation and the data was stored on an Excel sheet in which Dr. Chappell converted into ADD calculations for the burials. Photos were taken before burial and after exhumations with the use of a tri-pod and camera in order for photogrammetry to be performed in Agisoft Metashape (Agisoft 2019) for the purpose of creating better models for viewing the levels of decomposition and for use in a separate, unrelated research project. After placement of the donor and photographs were taken, the graves were then immediately filled in and graves were covered with chicken wire in order to prevent scavenging. The dates of burials and exhumations for each donor can be seen in Table 1.

Table 1. Burial and donor information for each grave.

Donor #	**Sex**	**Height (cm)**	**Weight (lbs)**	**Burial Depth**	**Burial Date**	**Exhumation Date**	**Days Buried**
2019.052	M	167.5	149	71 cm	9/10/2019	10/18/2019	38 days (1 month 8 days)
2019.042	M	178	238	73 cm	6/29/2019	9/12/2019	75 days (2 months, 2 weeks)
2019.038	M	177.5	178	75 cm	5/25/2019	9/22/2019	120 days (3 months, 3 weeks)
2019.033	M	186.5	187	70 cm	4/24/2019	9/1/2019	130 days (4 months, 8 days)
2019.036	M	172	148	75 cm	5/16/2019	10/18/2019	155 (5 months, 2 days)
2019.026	M	174.5	277	72 cm	3/26/2019	9/1/2019	159 days (5 months 6 days)

Donors were buried for time periods ranging from approximately one month to a little over 5 months. The first burial was placed on March 26, 2019 and the last September 10, 2019 (Table 1). Exhumation dates were conducted as close to the proposed end date for each time period as possible, however inclement weather, volunteer availability and scheduling conflicts caused for some time lengths to be longer or shorter than anticipated. For the exhumation of each burial, shovels, trowels and brushes were used to uncover the remains. Once enough dirt was removed from the surface and sides of the remains a water sprayer was used to remove any remaining dirt that was adhered to the remains in order to be able to score the state of decomposition better. After photographs and notes were taken for each of the exhumed bodies, the donors were repositioned and reburied for use in a separate, unrelated research project.

PMI Calculations/Statistics

Once the remains were exhumed a total body score was calculated using the descriptions provided by Megyesi et al. (2005) (Appendix A). The scores for each anatomical region (i.e., head and neck, torso, limbs) were summed to obtain the TBS.

Extra notes were also taken on the appearance and coloration of the remains, any insects present, presence of adipocere, condition of the soil surrounding the remains, and the overall moisture content of the head, torso and limbs of the buried remains. This information was used to provide data on the differences in the pattern between buried and surface remains and to make suggested changes in the descriptions.

Accumulated degree-days (ADD) were calculated two ways, one for surface temperatures using temperature data from the weather station located at Freeman Ranch, and another using the grave temperatures collected by the temperature probes that were placed inside the torso and underneath the body within each grave. Accumulated degree-days were calculated by adding up the average temperatures for each day from burial to exhumation, for both air and burial temperatures, in order to get the total ADD. These are identified as ADD_{air} and ADD_{burial}, respectively.

Using the Megyesi et al. (2005) method, the TBS for each donor was plugged into the provided equation ($ADD = 10^{(0.002*TBS*TBS+1.8)} \pm 388.16$), in order to obtain the predicted ADD, identified as $ADD_{Megyesi}$. This $ADD_{Megyesi}$ was then compared to ADD_{air} and ADD_{burial} using a Spearman's Rank test and a Pearsons correlation test in Microsoft Excel (2018). These tests were used in order to examine the monotonic relationship between the observed and estimated ADDs. Finally, a linear regression formula was run in Excel in order to test the relationship between the ADD_{burial} and TBS and ADD_{air} and TBS for all 6 burials, in order to see if ADD_{burial} can be used to predict TBS.

5. RESULTS

Decomposition and TBS

Overall burial decomposition throughout this sample was fairly consistent, with the majority of remains becoming desiccated with some skeletonization and adipocere formation on the underside of the body. Donor 2019.052 was buried for a total of 38 days from September to October, the shortest time period, and upon exhumation exhibited grey, green, black and brown discoloration, there was no exposed bone or bloat present, much of the face including the nose and ears were still intact, and the abdomen was only partially sunken in (Figure 4). No maggots or flies were present in this grave, but there were some white mites, possibly phoretic mites (Perotti & Braig 2009). After examining the state of decomposition using the Megyesi et al. (2005) method, the head and neck, trunk and limbs all fell within the stage of "early decomposition" corresponding to a TBS of 16, which correlates to an $ADD_{Meygesi}$ of 209.89 +/- 388.16 Celsius. The actual ADD_{air} for this individual is 978.73 Celsius and the ADD_{burial} is 1198.4 Celsius (Table 2).

Figure 4: Photogrammetry 3D rending of donor 2019.052 after exhumation produced in Agisoft MetaShape.

Donor 2019.042 was buried for a total of 75 days from June to September and exhibited similar grey, brown and black discoloration. The state of decomposition for this donor was in the advanced state with much of the tissue exhibiting desiccation and skeletonization of parts of the face, arms, hands, legs and feet (Figure 5). No maggots or flies were present in this grave, but there were some white mites, possibly phoretic mites (Perotti & Braig 2009). According to Megyesi et al. (2005), donor 2019.042's head and neck, trunk and limbs fall within the "advanced decomposition" state with a TBS of 24 and an associated estimated $ADD_{Meygesi}$ of 916.22 +/- 388.16 Celsius. The actual ADD_{air} for this individual is 2201.304 Celsius and the ADD_{burial} is 2915.61 Celsius.

Figure 5: Photogrammetry 3D rending of donor 2019.042 after exhumation produced in Agisoft Metashape.

Donor 2019.038 was buried for a total of 120 days from May to September and exhibited light brown and grey discoloration, with some areas of yellowish green and red. This tissue of this donor was much more desiccated, there was little to no adipocere present and there was more exposed bone as well (Figure 6). In this grave there were live and dead maggots, ants and the same white phoretic mites present. According to Megyesi et al. (2005), donor 2019.038's head and neck, and limbs fall within the "skeletonization" state and the torso falls within the "advanced decomposition" state coming out to a TBS of 27 and an associated estimated $ADD_{Meygesi}$ of 1853.53 +/- 388.16 Celsius. The actual ADD_{air} for this individual is 3405.057 Celsius and the ADD_{burial} is 4302.3 Celsius.

Figure 6: Photogrammetry 3D rending of donor 2019.038 after exhumation produced in Agisoft Metashape.

Donor 2019.033 was buried for a total of 130 days from April to September. Upon exhumation this individual exhibited white, light brown, grey and black discoloration similar to the other burials (Figure 7). There was less skeletonization and desiccation on this individual than that of the 120-day burial with donor 2019.038. In this grave there was the presence of both ants and white mites, but no maggots. According to the Megyesi et al. (2005) method, donor 2019.033's head and neck, torso and limbs fall within the "advanced decomposition" stage with a TBS of 21 and an associated $ADD_{Meygesi}$ of 492.04 +/- 388.16 Celsius. The actual ADD_{air} for this individual is 3510.81 Celsius and the ADD_{burial} is 4294.7 Celsius.

Figure 7: Photogrammetry 3D rending of donor 2019.033 after exhumation produced in Agisoft Metashape.

Donor 2019.036 was buried for a total of 155 days from May to October. This individual exhibited black, dark brown and dark green discoloration and was the most desiccated and skeletonized out of all of the burials (Figure 8). No maggots or flies were found in this grave, only the white mites and ants. According to the Megyesi et al. (2005) method this donor's head and neck, torso and limbs were all considered to be in the "skeletonized" stage with a TBS of 28. The $ADD_{Meygesi}$ for 2019.036 is 2387.81 +/- 388.16 Celsius yet the actual ADD_{air} for this individual is 4279.304 Celsius and the ADD_{burial} is 5118.7 Celsius.

Figure 8: Photogrammetry 3D rending of donor 2019.036 after exhumation produced in Agisoft Metashape.

Lastly, donor 2019.026 was buried for a total of 159 days from March to September. This individual exhibited grey and black discoloration, with the most amount of adipocere present out of all of the graves and little exposed bone (Figure 9). No maggots, flies or ants were found in this grave, only the white mites seen in all other graves. According to the Megyesi et al. (2005) method this donor's head and neck, torso and limbs all fall within the "advanced decomposition" stage with a TBS of 20. The $ADD_{Meygesi}$ for 2019.026 is 407.38 +/- 388.16 Celsius yet the actual ADD_{air} for this individual is 4048.95 Celsius and the ADD_{burial} is 4904.6 Celsius.

Figure 9: Photogrammetry 3D rending of donor 2019.026 after exhumation produced in Agisoft Metashape.

Statistical Results

The correlation based on Spearman's rank test to assess the relationships between the predicted $ADD_{Meygesi}$ and the actual ADD_{air} for all six graves was 0.314. The Pearsons correlation for these two variables was 0.474. A Spearman's rank and Pearsons test were also run to test the relationship between the predicted $ADD_{Meygesi}$ and the $ADD_{burials}$ and a correlation coefficient of 0.6 for the Spearman's rank, and 0.533 for the Pearsons correlation. This shows that there is not a strong correlation between the predicted ADD values from the Megyesi et al. (2005) method and the actual ADD values from the above ground and burial temperatures (Figure 10) (Table 2). A Spearman's rank and Pearsons test were run to test the correlation between ADD_{air} and ADD_{burial} and the Spearman's rank coefficient was 0.886, with a Pearsons correlation coefficient of 0.921. These results show that there is a strong correlation between the ADD values from above ground and burial temperatures (Figure 11). A linear regression formula was run to test the relationship between TBS and ADD_{burial} in order to get a regression equation using TBS as the independent value and burial temperatures as the dependent value. The R squared value for these variables was 0.4104 with a linear regression equation of $Y = 209.07x - 949.98$, meaning TBS only account for about 40% of the ADD_{burial} temperature variation (Figure 12)(Appendix B). A linear regression formula was run to test the relationship between TBS and ADD_{air} as well, in order to get a regression equation for air temperatures as the dependent value. The R squared value for this equation was 0.2046 with a linear regression equation of $Y= 88.787x + 1262.3$, meaning TBS only accounted for about 20% of the ADD_{air} temperature variation (Figure 13)(Appendix C). Table 3 shows the results for the predicted ADD values when TBS is plugged into the linear equations calculated from the ADD_{burial} and ADD_{air} values. The relatively small sample size of this research project should be taken into account when assessing these statistical results.

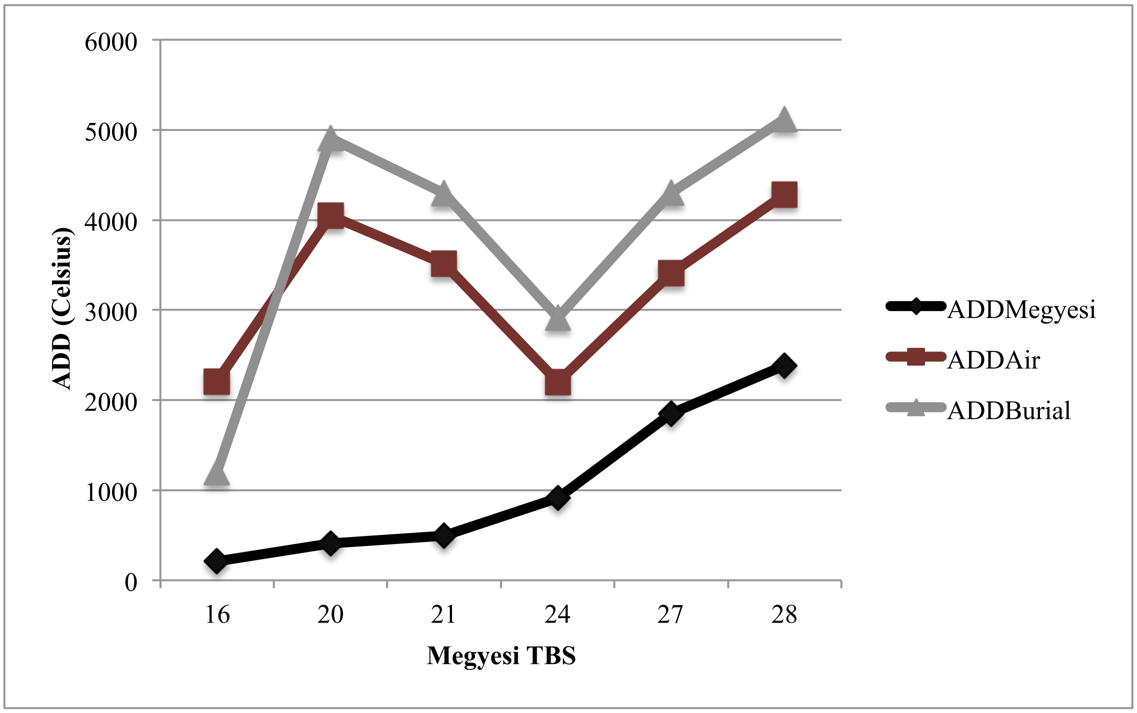


Figure 10: ADD in Celsius for above ground and burial temperatures and the predicted Megyesi et al. (2005) method organized by TBS.

Table 2: $ADD_{Meygesi}$, ADD_{air}, and ADD_{burial} results for each burial in Celsius.

Donor #	ADDMegyesi	ADDAir	ADDBurial	TBS
2019.026	407.38	4048.95	4904.6	20
2019.033	492.04	3510.81	4294.7	21
2019.036	2387.81	4279.304	5118.7	28
2019.038	1853.53	3405.057	4302.3	27
2019.042	916.22	2201.304	2915.61	24
2019.052	209.89	2203.508	1198.4	16

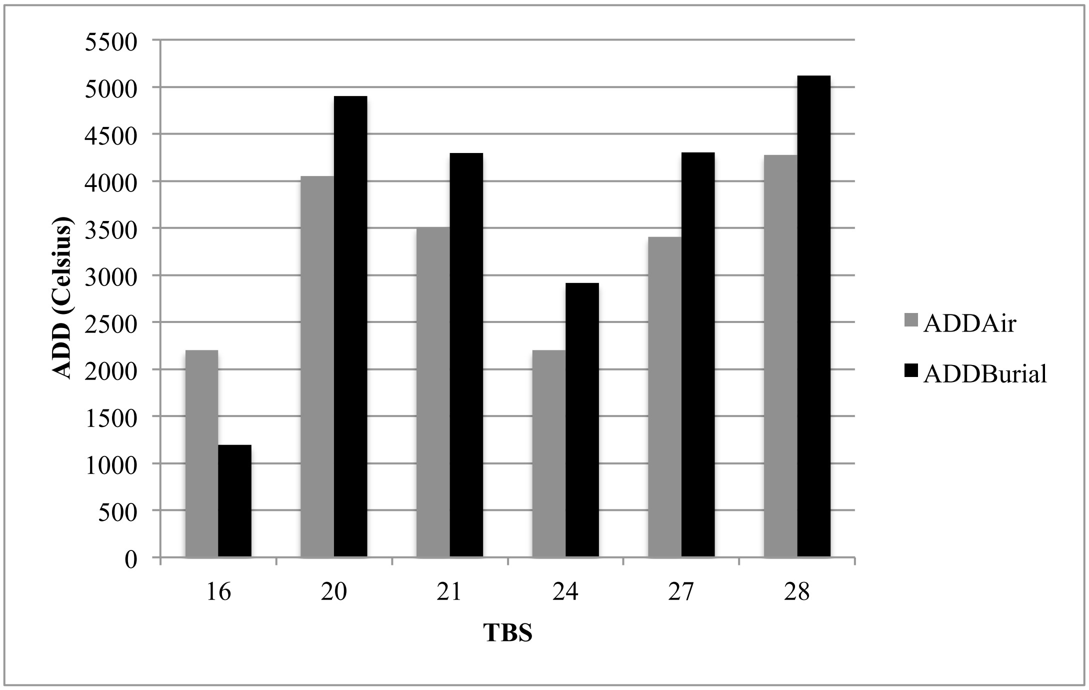


Figure 11: ADDair compared to ADDburial by TBS for each burial.

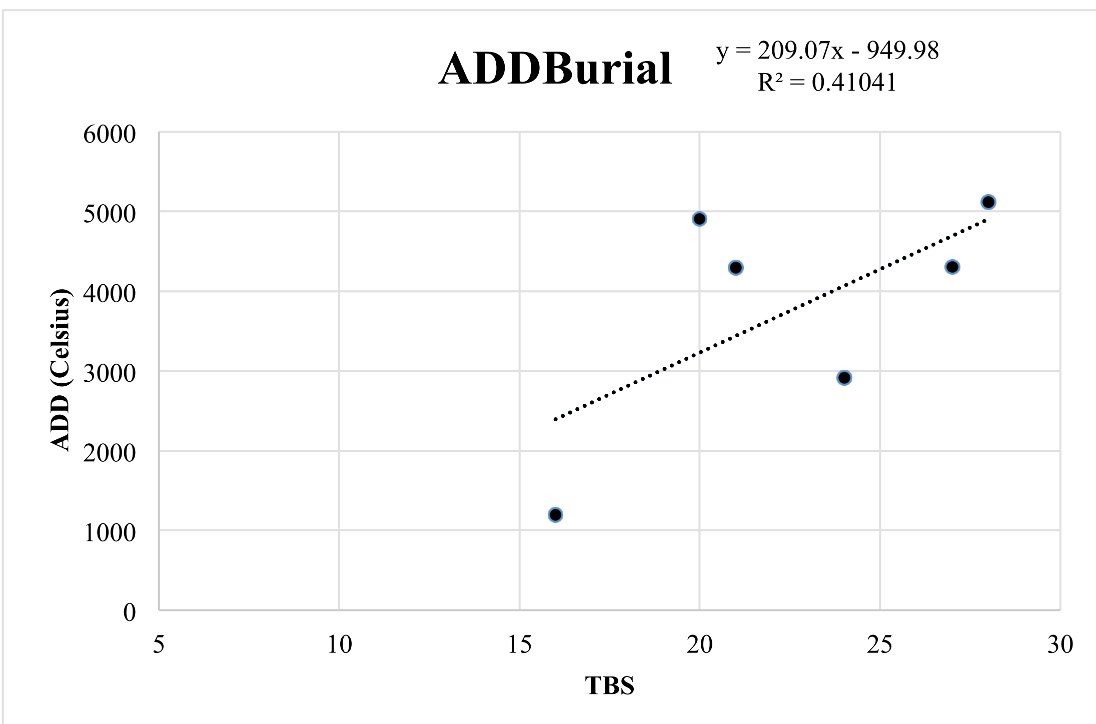


Figure 12: Linear regression line and equation for the relationship between TBS and ADDburial temperatures for each burial.

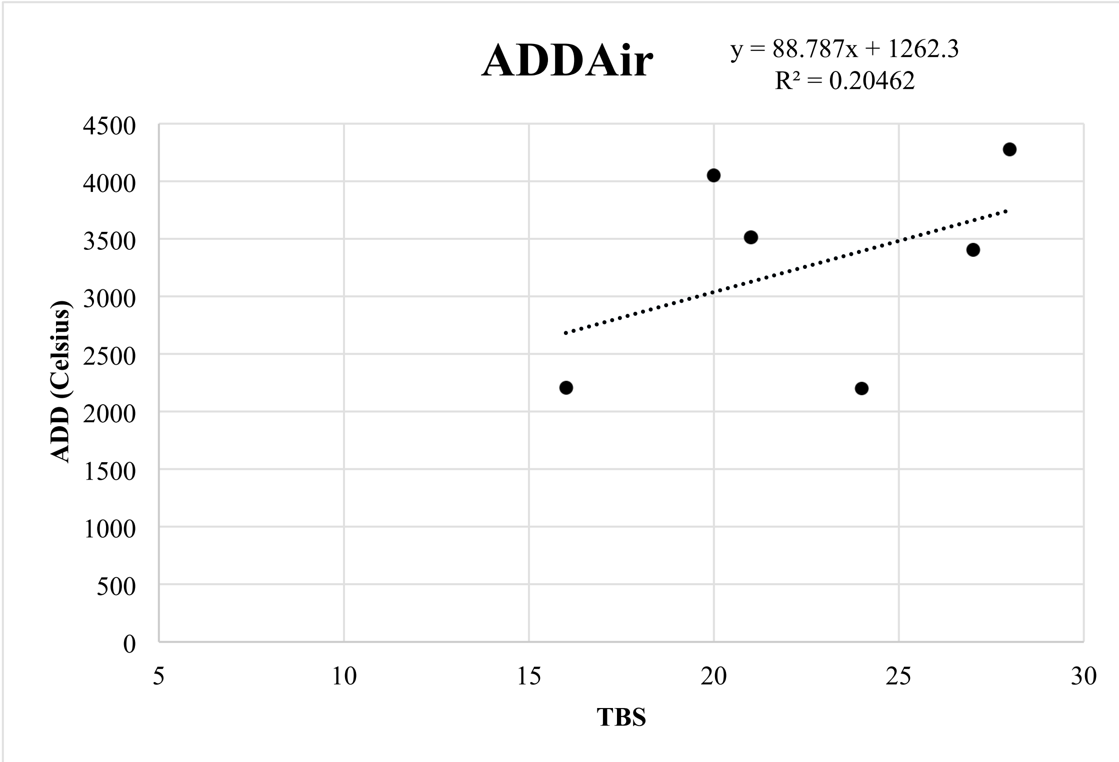


Figure 13: Linear regression line and equation for the relationship between TBS and ADD_{air} temperatures for each burial.

Table 3: Predicted ADD values using TBS as X in the linear equations provided by the ADD_{air} and ADD_{burial} temperatures, compared to the actual ADD_{air} and ADD_{burial} values.

TBS	Predicted ADDburial	Actual ADDburial	Predicted ADDair	Actual ADDair
16	2395.14	1198.4	2682.892	2203.508
20	3231.42	4904.6	3038.04	4048.95
21	3440.49	4294.7	3126.827	3510.81
24	4067.7	2915.61	3393.188	2201.304
27	4694.91	4302.3	3659.549	3405.057
28	6803.94	5118.7	3748.336	4279.304

6. DISCUSSION

Comparison to Surface Remains

Surface decomposition is extremely variable even within similar climates and seasons since there are often more variables than burial settings that can affect the rates and patterns of decomposition. Thus, when burial decomposition is compared to surface remains it is only possible to talk about common trends seen within a similar environment. For the decomposition environment of Central Texas, specifically that of the Forensic Anthropology Research Facility in San Marcos, Texas during the summer months, surface remains typically decompose rapidly in the beginning and quickly reach advanced stages of decomposition, such as mummification. In addition, bone exposure has been recorded occurring within 4 days of placement if scavenger activity is allowed (Sears 2013; Suckling 2011).

Since the donors for this research project were buried for a set period of time and were not exhumed throughout that time period it is not possible to determine the exact dates they reached bloat, adipocere formation, mummification or skeletonization. Also since the shortest burial was 38 days, most surface remains have gone through the early and even advanced stages of decomposition (Galloway et al. 1989; Megyesi et al. 2005; Sears 2013; Suckling 2011, Bates 2014), making it difficult to directly observe aspects of decomposition such as bloat, purge, skin slippage or marbling in the buried remains from this study. We can compare the ADDs of surface remains from previous research to those of the buried remains in this study. For example, Donor 2019.052, the 38-day burial, still exhibited partial bloat and was considered to be in the "early" stage of decomposition according to the Megyesi et al. (2005) method. Yet, this donor had an ADD_{air} of 978.73

Celsius and an ADD_{burial} of 1198.4 Celsius, whereas in a study conducted by Bates (2014) found that non-autopsied remains at FARF in the spring/summer months usually reached early decomposition at an ADD of around 116.8 Celsius. This suggests that the decomposition rate of buried remains is slower than that of surface remains, but if adipocere is not formed, bodies follow similar patterns of decomposition and discoloration just as dissimilar, slightly slower time lengths.

As can be seen in the shortest burial duration of 38 days, the skeletonization stage or any bone exposure at all was not reached, and the tissue retains a fair amount of moisture. Yet, the other five burials did exhibit some form of skeletonization, especially on the lower limbs. With surface remains at FARF during these time periods, bone can become exposed within 24 hours of placement if there is scavenger activity, and full skeletonization of a body can be seen within 12 days, but is more commonly seen around the one to two month mark (Suckling 2011). The study conducted by Bates (2014) also found that non-autopsied surface remains at FARF can reach advanced decomposition at approximately an ADD of 297.6 or mummification at an ADD of around 175.9 Celsius, whereas the ADD_{air} and ADD_{burial} for the buried individuals in this study that reached advanced decomposition or skeletonization were all well over 4000 ADD Celsius. Although surface remains in the summer at FARF do not always reach skeletonization, like the study done by Sears (2013) that found out of 40 donors placed on the surface, only one reached full skeletonization and only 6 reached partial skeletonization. Therefore, skeletonization can be dependent on a multitude of factors such as scavenger activity, temperature, rainfall levels and sun exposure. These factors can therefore pose issues when estimating PMI using methods for surface remains since skeletonization may be occurring at a slower, yet more consistent, rate in burials. One similarity between the skeletonization seen in the buried remains and among surface remains was the aspects of the body most affected. In both burial and surface remains skeletonization was seen the most frequently on the limbs and head (Sears 2013; Suckling 2011), likely due to the thin nature of the tissue and lack of internal organs on these regions of the body.

The majority of the buried remains exhibited extensive desiccation of tissue on the anterior portions of the body, with adipocere on the posterior sides of some of the burial donors. The donor in the 159-day burial exhibited the highest amount of adipocere formation on both the anterior and posterior sides of the head, neck, torso and upper limbs, with some bone exposure of the lower limbs. Whereas the donor from the 120-day burial had no adipocere present, the tissue was extremely desiccated and there was bone exposure on all aspects of the body. All of the other burials exhibited some extent of desiccation or mummification evident by a drying out and wrinkling of the tissue, especially on the limbs and face. For surface remains at FARF, full mummification has been documented at 241 ADD to 1698 ADD by Sears (2013) or as early as 175.9 ADD by Bates (2014). Again, since mummification appears to happen quicker in surface remains at FARF, this can affect PMI calculations for buried remains.

One of the major differences between the decomposition of buried remains versus surface remains at FARF during the summer months is the formation of adipocere. As discussed before the individual in the 159 day burial was almost completely covered in adipocere, and almost all other burials with the exception of one had adipocere formation on the posterior sides. Adipocere is something that is not typically seen in surface remains since it needs a moist, anaerobic environment to form (Schotsmans et al. 2010;

Forbes et al. 2004; Fiedler & Graw 2003; Vass 2011; Ubelaker & Zarenko 2011). This is supported by the surface decomposition studies conducted out at FARF, as they did not note adipocere formation on any donors (Sears 2013; Suckling 2011). In the case of the 159-day burial where there was extensive adipocere formation, the TBS was only 20, a vast underestimation, since the actual ADD_{air} was 4048.95 Celsius and the ADD_{burial} was 4904.6 Celsius. Adipocere in burial contexts is comparable to that of mummification on surface remains because once it forms and if the environment is not changed it will slow, and even halt, any further decomposition (Ubelaker & Zarenko 2011). The problem with these burials and estimating TBS and thus PMI though is that the majority of them exhibited both adipocere formation and mummification. Therefore even though donors 2019.026 (159 days) and 2019.036 (155 days) were buried for almost the same amount of time, since 2019.026 formed adipocere on anterior side as well as the posterior side they had a TBS of only 20 compared to a TBS of 28 for 2019.036, which had partially mummified and skeletonized. Lastly the issue with using the Megyesi et al. (2005) method of calculating PMI is that the descriptions for the stages of decomposition are highly based on discoloration. While the discoloration of buried remains is somewhat similar to that of surface remains in that we seen green, gray and black discoloration, the presence of soil staining on the buried remains can make it difficult to view the actual extent of discoloration.

Temperature

As observed in Figure 11 above, temperatures within the burials were similar to the above ground temperatures and were significantly correlated (Spearmans: 0.886 Pearsons: 0.921). All of the burial temperatures within the abdomen of the donors show a rapid increase in temperature at the beginning of decomposition and then a gradual leveling of temperature throughout the duration of the burial, with a slight decrease in temperatures near the exhumation dates (Appendix C). This temperature change throughout decomposition is similar to that of surface remains and is the result of the normal putrefaction that occurs during the decomposition of organic materials (Bates 2014). Although grave temperatures did stay somewhat close to the above ground temperatures, one main difference noticed was that burial temperatures remained much more constant overtime and were not subjected to the higher fluctuations in temperatures that were seen above ground. Figures 13 and 14 are an example of burial temperatures from 2019.026, the 159-day burials as well as the observed above ground temperatures for that same area and time period.

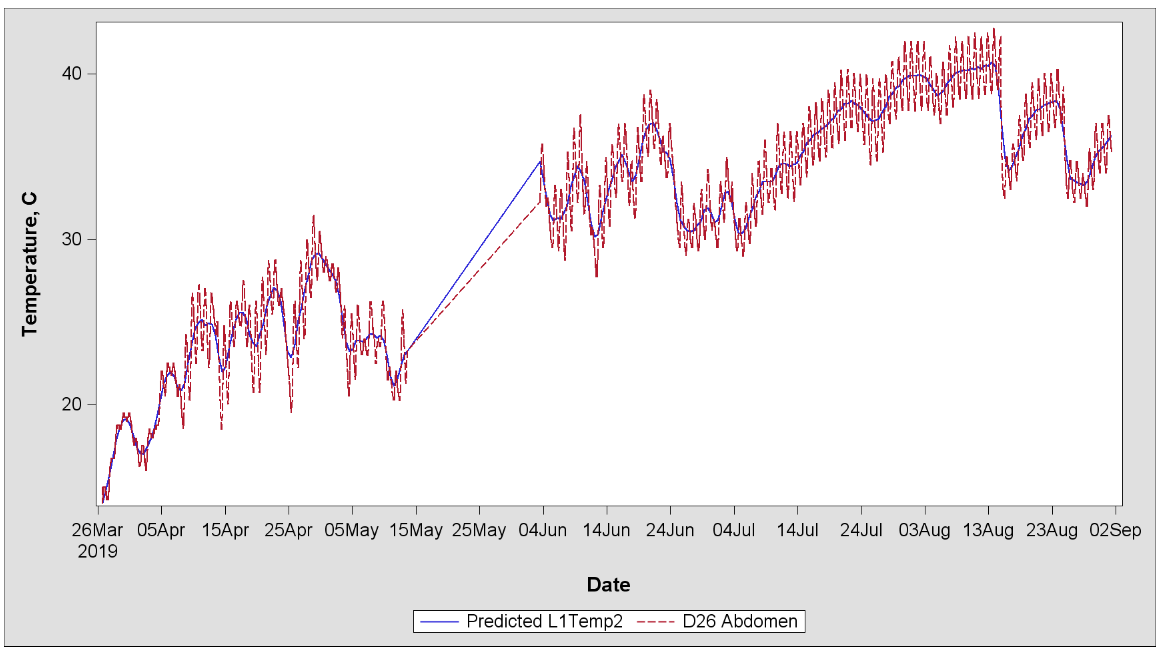


Figure 14: Burial temperature data from inside the abdomen of donor 2019.026 from March to September in degrees Celsius. Red line indicates actual temperatures readings and blue line indicates the predicted temperature model. There is a gap in data from May 15th to June 4th due to temperature logger malfunction.

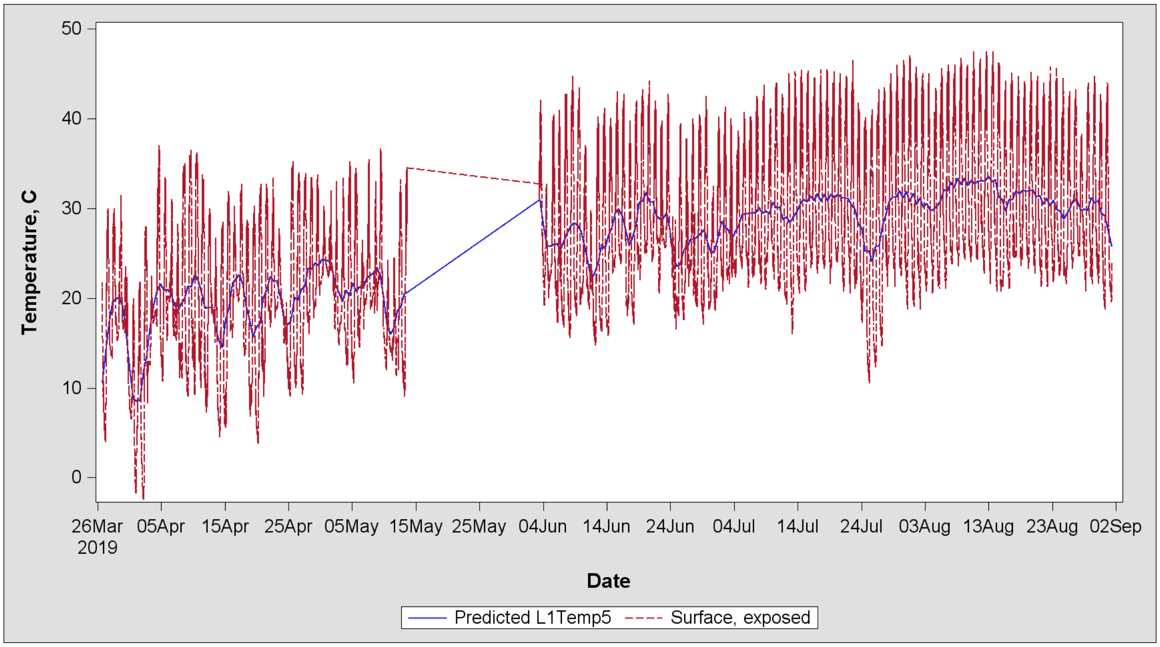


Figure 15: Surface temperature data above the grave of 2019.026 from March to September in degrees Celsius. Red line indicates actual temperatures readings and blue line indicates the predicted temperature model. There is a gap in data from May 15th to June 4th due to temperature logger malfunction.

As you can see in these two graphs there was much more fluctuation of highs and lows on the surface of the graves than there was inside the abdomen of the buried individual. This suggests that burial temperatures are more consistent over time, which could provide for a more stable and steady decomposition environment, something that is consistent with previous studies on burial decomposition (Vass 2011; Fiedler and Graw 2003; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner and Wiltshire 1999; Wilson et al. 2006). The correlation between ADD_{air} and ADD_{burial} was consistent, yet the linear regression equation between ADD_{burial} and TBS and ADD_{air} and TBS was not strong, therefore suggesting a need for improvement in the Megyesi et al. (2005) TBS scoring system. Again, though the small sample size of the project could have an effect on these statistical results and increasing the sample size may provide stronger liner equations for estimating ADD from TBS scores. Also, the shallowness of these graves could account for the similarity between ambient and grave temperatures and thus deeper graves may have different temperature results.

Since burial temperatures remained somewhat consistent throughout the burial durations and since each burial was relatively close in temperature to the other burials (within the range of 20 to 40 degrees Celsius), the significant amount of adipocere formation on donors 2019.026 (159-day burial) and 2019.033 (130-day burial) as compared to the other burials could be the results of precipitation levels. These two donors were buried in late March, early April and remained buried until September 1st, during which the majority of rainfall occurred. As shown in Figure 16 below these two donors experienced the most accumulated rainfall levels as compared to the other burials, which could explain why they had the most adipocere formation even though their burial temperatures were relatively similar to the other burials. Although it is possible that the relatively high BMI of donor 2019.026 had an impact on the level of adipocere formation as well. Yet previous studies on adipocere have shown that moisture content can be one of the main factors that affect the formation and preservation of adipocere, especially within burials (Schotsmans et al. 2010; Forbes et al. 2004; Fiedler & Graw 2003; Vass 2011; Ubelaker & Zarenko 2011).

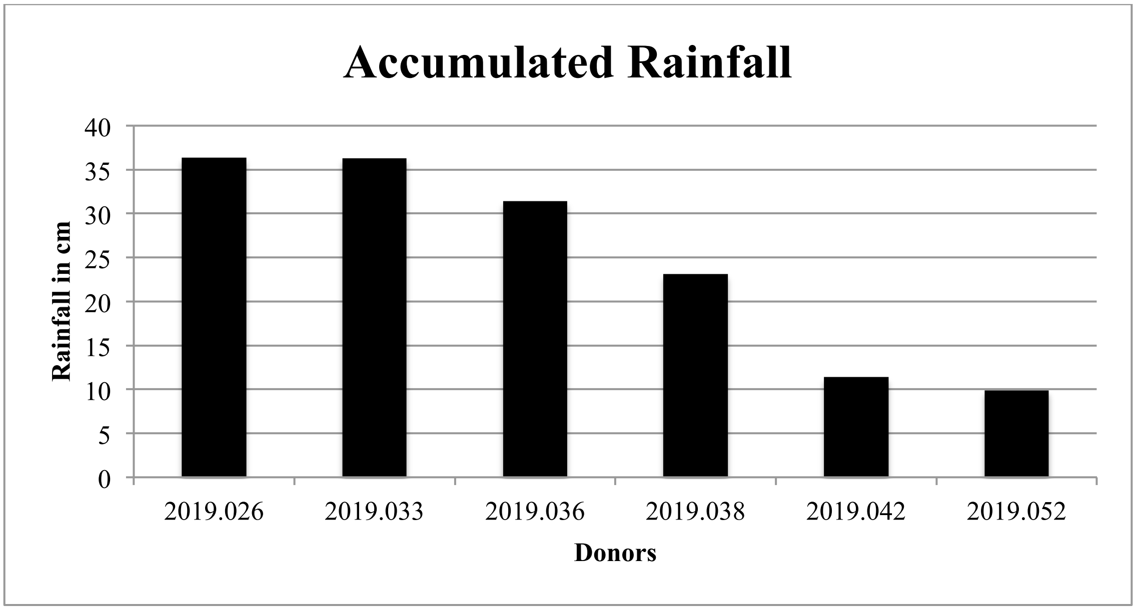


Figure 16: Accumulated rainfall levels in cm from the duration of the burials for each buried donor.

Typically soils with high clay content can aid in the preservation of tissues and formation of adipocere because they retain water (Bryan and Wiltshire 1999; Rodriguez 1997), whereas the rumple soil type seen at FARF is typically considered to be well draining (Carson 2000). Although upon exhumation of the burials of donor 2019.026 and 2019.033 (March and April burials, respectively) there was stagnant water noticed on the grave floor. Also after the graves were dug, prior to placement and burial, there were puddles that formed within the graves after moderate rainfall, suggesting that the soil in which the graves were dug retains water. This could be due to the fact that the ground out at FARF, and throughout much of Central Texas, is very rocky making it difficult for the soil to drain quickly. Also, since the soil of the graves was disturbed during burial it was less compact that the surrounding soil of the grave floor and walls which could have caused for more water to drain into the graves around the remains (Carson 2000).

Although burial temperatures were fairly consistent throughout all of the burials, and the ADD_{burial} temperatures were slightly higher than the actual ADD_{air} temperatures, the 38-day burial of donor 2019.052 showed somewhat lower burial temperatures than the other graves (Figure 11). This could be due to the fact that this donor was buried during the month of October, in which the lowest above ground temperatures were recorded as compared to the other burial durations. This individual showed no signs of skeletonization, adipocere formation or insect activity, which could be the result of the cooler temperatures or it could be due to the fact that this was the shortest burial duration and therefore not enough time had passed for these decomposition processes to happen.

Moisture Content

Temperature may not be the most helpful tool for estimating PMI for buried remains, given grave temperatures would not be available in a forensic case. This study and prior studies clearly show that the Megyesi et al. (2005) ADD estimation method is not accurate for buried remains (Janaway 1996; Mann et al. 1990; Marais-Werner et al. 2017; Schotsmans et al. 2010; Schultz 2007; Simmons et al. 2010; Turner & Wiltshire 1999; Wilson et al. 2006; Vass 2011). Therefore, moisture content and grave environment may be more applicable when trying to estimate PMI for buried remains, especially when moisture content is relatively easier to observe on buried remains than discoloration is. In this study, upon exhumation, the graves of burials 2019.026, 2019.033 and 2019.036 had much more compact, moist soil than the other three graves, likely due to the amount of rainfall that occurred during the duration of these burials. Whereas the burial of donor 2019.038 had much dryer, looser soil upon exhumation. Interestingly donor 2019.038 had the second highest TBS of 27, even though this individual was only buried for a total of 120 days. This high TBS in congruence with more exposed bone and desiccated tissue as compared to some of the other donors that were buried for a longer period of time could be due to the precipitation levels and moisture content in the soil. Since precipitation levels were lower for this burial duration the dryer surrounding soil could have absorbed more moisture from the remains, causing them to desiccate and reach a later stage of decomposition according to the TBS scoring system (Megyesi et al. 2005).

Another aspect noticed with the moisture content of the soil upon exhumation was the presence of cave-like soil formations around the remains of some of the burials (Figure 17). This cave-like structure appeared to be the result of adipocere mixing with the surrounding soil when the donors were in the full bloat stage, since it was not observed in the graves that had zero adipocere formation. After the donors purged decompositional fluids and began to enter the post-bloat and mummification/ skeletonization phases of decomposition these "adipocere caves" retained their shape, creating an air pocket around the anterior surface of the remains. The presence of these cave-like structures shows how the soil can retain moisture even after the body has purged and begun to desiccate. As well, the creation of an air pocket around the remains due to this structure could have aided in the further desiccation of the buried remains. The only two graves where this cave-like pocket was not seen were in donors' 2019.036 and 2019.038 (both May burials) the two donors with the highest TBS. This could suggest that either these adipocere caves did not form in these graves, or that after decomposition reaches later stages these cave-like pockets dry out and collapse in on the remains. Further understanding of how and when these cave-like soil structures form within the graves in relation to soil type and moisture levels could help investigators estimate PMI by acknowledging the presence of bloat, post bloat, adipocere formation and adipocere loss throughout the duration of the burial.

Figure 17: Image taken by Ariel Spaulding of cave-like structure noticed during the exhumation of the burial of donor 2019.033

Insect Activity

Several types of insects were present among all of the graves. Of the insects present there were *Hermetia illucens* (or solider fly) larvae, some dead and some living, small white mites, possibly phoretic mites, and ants. The white mites were present in every grave upon exhumation, but ants were only present in the graves of donors 2019.033, 2019.036 and 2019.038, and the maggots were only present in the grave of donor 2019.038. The white mites are likely phoretic mites, which are often seen in association with human and animal decomposition because they often travel on scavenger insects (Perotti & Braig 2009). The presence of maggots in the 2019.038 grave could have been the result of adult flies laying eggs during the brief period between placement and burial, or they could have accessed the remains after burial due to the loose and rocky nature of the soil, which allowed some air pockets and access for the flies to enter the graves. The presence of maggots in this grave could explain why this burial had the second highest TBS despite only being buried for 120 days, since maggots are known to accelerate the decomposition process (Simmons et al. 2010). Since the grave temperatures stayed fairly consistent throughout and the coverage from the soil protects insects from intense solar radiation and scavenging, this could have provided a very habitable environment for the maggots to thrive. Although there were insects present among the graves, since the date of colonization is unknown and not every grave had the presence of maggots it is not possible to estimate PMI using larvae for these buried remains (Turner & Wiltshire 1999).

7. CONCLUSION

Understanding how human remains in shallow burials decompose differently from that of surface remains in both time length and decomposition trends remains an important topic for both anthropological and forensic applications. Factors such as insect access, temperature, moisture and adipocere formation can all have an affect on the rates of decomposition for buried remains, often causing them to decay at a slower rate. These factors can thus affect TBS scores and subsequently PMI estimations if buried remains are found in a forensic setting.

The main goal of this study was to identify the factors that affect the decomposition of human remains in shallow burials in comparison to surface remains in Central Texas, assess the validity of the Megyesi et al. (2005) PMI estimation method, and offer suggestions for future research on PMI estimations for buried remains using temperature data and other factors observed. Based on the results there is not a significant correlation between the estimated ADDs using the Megyesi et al. (2005) method and the actual ADD values from the air and grave temperatures. In all cases the TBS significantly underestimated the actual ADD. There was a significant correlation between the ADD values of the air and grave temperatures though, which suggest that even though grave temperatures remain more constant and are not exposed to solar radiation, they are still relatively similar to the above ground temperatures. Although there was not a significant relationship between burial ADDs and the TBS gathered using the Megyesi et al. (2005) method, suggesting this method needs improvement in descriptions in order to have more accurate TBS for buried remains. Based on the observation of the six burials, it is clear that the TBS needs to be adjusted based on the presence or absence of adipocere and possibly include a score for insect activity. Like above ground decomposition, decomposition rates for burials may also be influenced by the season of death (Bates 2014).

In this study buried remains did decompose slower than that of surface remains observed in Central Texas in previous studies, although it was apparent that the buried remains were still able to reach advanced stages of decomposition even after only 2 months. It was also observed that in the rainier months there was more adipocere formation in the graves than of those that were buried in the dryer months of the summer. Finally there was still some insect activity present in some of the burials, in which the TBS scores were higher than that of those with no maggot activity, suggesting that insect access is still available and can affect decomposition rates of buried remains.

Future Research

The results of this study further reinforce that buried remains decompose at a different rate than surface remains in Central Texas and that the Megyesi et al. (2005) method of estimating TBS and thus PMI is not applicable for buried human remains. Yet the sample size of this study is relatively small and thus statistical tests can be skewed, making it important to conduct further studies of how human remains decompose in shallow burials with more individuals. Another suggestion for future research would be to collect actual moisture composition data from each burial in combination with temperature data in order to see if this has a more significant effect on the rates of decomposition. Also, since decomposition is so variable, it is important to conduct more research studies on the decomposition of buried remains in different climates, environments and seasons.

APPENDIX SECTION

APPENDIX A: Total body scoring method based on appearance of decomposition for the head, torso and limbs from Megyesi et al. (2005).

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

Trunk			
Fresh	**Early**	**Advanced**	**Skeletonization**
Fresh, no discoloration (1pt)	Pink-White appearance with skin slippage and marbling present (2pts)	Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity (6pt)	Bone with decomposed tissue, sometimes with body fluids and grease still present (9pts)
	Gray to green discoloration: some flesh still relative fresh (3pts)	Moist Decomposition with bone exposure less than one half that of the area being scored (7pts)	Bones with desiccated or mummified tissue covering less than one half of the area being scored (10pts)

	Bloating with green discoloration and purging of decompositional fluids (4pts)	Mummification with bones exposure less than one half that of the area being scored (8pts)	Bones largely dry, but retaining some grease (11pts)
	Post bloating following release of the abdominal gases, with discoloration changing from green to black (5pts)		Dry bone (12pts)
Limbs			
Fresh	**Early**	**Advanced**	**Skeletonization**
Fresh, no discoloration (1pt)	Pink-White appearance with skin slippage of hands and/or feet (2pts)	Moist decomposition with bone exposure less than one half that area being scored (6pts)	Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining (8pts)
	Gray to green discoloration; marbling; some flesh still relative fresh (3pts)	Mummification with bones exposure less than one half that of the area being scored (7pts)	Bones largely dry, but retaining some grease (9pts)
	Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities (4pts)		Dry Bone (10pts)
	Brown to black discoloration, skin having leathery appearance (5pts)		

APPENDIX B: Regression Analysis results for ADD_{burial} compared to TBS in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.640633448
R Square	0.410411214
Adjusted R Square	0.263014018
Standard Error	1273.670998
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4516942.021	4516942.021	2.784389557	0.170511404
Residual	4	6488951.245	1622237.811		
Total	5	11005893.27			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-949.9809355	2887.249407	-0.329026281	0.758642182	-8966.27042
X Variable 1	209.0749677	125.295952	1.668649021	0.170511404	-138.802365

Upper 95%	*Lower 95.0%*	*Upper 95.0%*
7066.308549	-8966.27042	7066.308549
556.9523004	-138.802365	556.9523004

APPENDIX C: Regression analysis results for TBS compared to ADD_{air} in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.452345893
R Square	0.204616807
Adjusted R Square	0.005771008
Standard Error	889.7291238
Observations	6

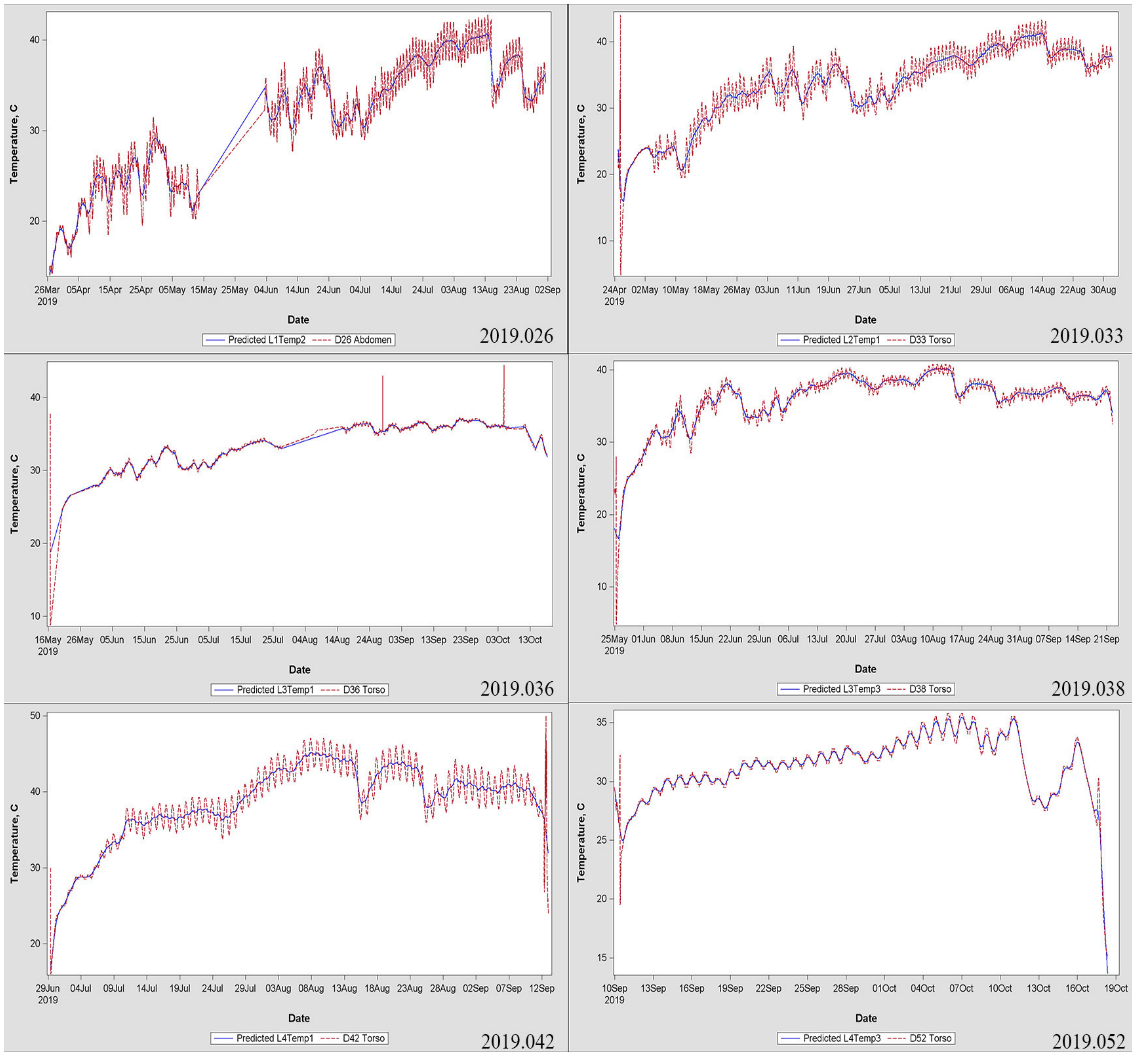
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	814592.6683	814592.6683	1.02902253	0.367759947
Residual	4	3166471.655	791617.9137		
Total	5	3981064.323			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	1262.313835	2016.902237	0.625867636	0.565340625	-4337.504508
X Variable 1	88.78713226	87.52610193	1.014407477	0.367759947	-154.224285

Upper 95%	*Lower 95.0%*	*Upper 95.0%*
6862.132179	-4337.504508	6862.132179
331.7985495	-154.224285	331.7985495

APPENDIX D: Torso temperatures from all 6 burials.



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