THE EFFECT OF PLASTIC TARPS ON THE RATE OF HUMAN DECOMPOSITION DURING THE SPRING/SUMMER IN CENTRAL TEXAS

by

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LIST OF ABBREVIATIONS

FACTS	Forensic Anthropology Center at Texas State
FARF	Forensic Anthropology Research Facility
ADD	Accumulated Degree Days
ARF	Anthropology Research Facility
PMI	Postmortem Interval
TBS	Total Body Score

ABSTRACT

Forensic anthropological literature cite that bodies are commonly covered or wrapped in man-made materials for disposal and concealment. Therefore, knowing if there are differences in the rate of decomposition between tarp and control bodies is important for forensic scientists conducting postmortem interval estimations. While several studies have been conducted on the effects of decomposition when the body is covered or wrapped in materials such as clothing, blankets, and plastic tarps, most of these studies have examined a variety of coverings simultaneously with relatively small sample sizes and use pig surrogates. Therefore, the purpose of this study is to conduct a controlled investigation of the effect of plastic tarps on the rate and pattern of human decomposition in Central Texas using a relatively large sample size. Unlike previous studies, this study utilized only one type of covering, the sample size was larger than previously examined, and environmental conditions and dates of death are known.

Human remains covered or wrapped in a tarp provides an ideal environment for decomposition since the tarp may maintain moisture and temperature while providing insects and bacteria protection from predators and environmental factors. Therefore, it was hypothesized that the plastic tarp would aid in decomposition in two ways: 1) by increasing the activity of necrophagous insects, which prefer a warm, shaded and outdoor environment and 2) by increasing putrefaction caused by bacteria that require an aqueous medium. The increased activity of insects and bacteria should therefore likely increase the rate of decomposition. In other words, require fewer accumulated degree days

(ADD) to reach each stage of decomposition.

This study showed that remains wrapped in plastic tarps had a statistically significant effect on the rate of human decomposition when compared to unwrapped remains in a Central Texas environment. Since the null was rejected further examination occurred and found that temperature was not a significant contributing factor for the change in rate of decomposition. However, insect activity was observed as a contributing factor since it was a constant throughout the entire study period for all wrapped remains. This study will contribute to the field of forensic anthropology by providing reliable information about the effect wrapping bodies in plastic tarp material has on the decomposition rate in Central Texas. Law enforcement and other forensic scientists should be very cautious if using the Megyesi et al. (2005) method and be fully aware of its limitations and inconsistent results.

I. INTRODUCTION

Multiple studies have been conducted on the decomposition of human remains, but the research that has examined the effects of decomposition when remains are covered or wrapped in various materials (e.g., clothing, blankets, and plastic tarps) have relatively small sample sizes and most use pig surrogates (see Bell, 2012; Dautartas, 2009; Kelly et al. 2009; Shattuck 2009; Hyder 2007; Cahoon 1992; Goff, 1992; Miller, 2002; Phalen, 2013; Voss et al., 2011; Matuszewski et al. 2014). However, the forensic anthropological literature cite that bodies are commonly covered or wrapped in man-made materials for disposal and concealment (Forbes et al., 2009; Komar, 2003; Manhein, 1997). Knowing the differences in decomposition rates between wrapped and unwrapped bodies and the possible causal factors for the difference is important for forensic scientists that provide postmortem interval (PMI) estimations. Therefore, the purpose of this study is to conduct a controlled study to investigate the decomposition rates of bodies wrapped in plastic tarp materials. Unlike previous studies, this study utilized only one type of covering, the sample size was larger than previously utilized, and environmental conditions and dates of placement are known. This study will contribute to the field of forensic anthropology by providing reliable information about the effect wrapping bodies in plastic tarp material has on the decomposition rate in Central Texas.

In this study, I examined differences in the rate of decomposition between human remains wrapped in plastic tarps compared to unwrapped bodies. I hypothesized that human remains wrapped in plastic tarps and placed on the ground surface would decompose at a significantly faster rate than bodies not wrapped in plastic tarps. Human

remains covered in a tarp provide an ideal environment for decomposition since they may maintain a moist environment, conserve temperature and provide protection for insects and bacteria. Therefore, the plastic tarp should aid in decomposition in two ways: 1) by increasing the activity of necrophagous insects, which prefer a warm, shaded and outdoor environment (Shirley et al., 2011; Clark et al., 1997), and 2) by increasing enzymatic decay (autolysis) and putrefaction by bacteria that require an aqueous medium (Gill-King, 1997). The increased activity of insects and bacteria would therefore likely increase the rate of decomposition (i.e., require fewer accumulated degree days).

My main question is whether decomposition rates are significantly different between bodies placed on the ground surface wrapped and not wrapped in plastic tarps. My reasoning for choosing the plastic tarp as the material in my study is because it is commonly cited in the literature as a material to conceal the body during disposal (Komar, 2003; Manhein, 1997) and because it is a material that is readily available in most U.S. markets. Accumulated degree days (ADD) and total body score (TBS) (Megyesi et al., 2005) were used to compare the decomposition rates. My null hypothesis was that there is no significant difference in TBS between wrapped and unwrapped bodies after 500, 1000, 1500, and 2000 ADD (based on the local external ambient temperature). If my null hypothesis is rejected, then I would examine if temperature contributed to the change in decomposition rate. Five hundred ADD was chosen because previous research at FARF indicates that mummification occurs on average around 500 ADD during spring and summer months (Bates, 2014). Since there is limited research on whether a difference in decomposition exists when plastic material

is used to dispose of human remains, this study will contribute to the field of forensic anthropology specifically PMI estimations.

BACKGROUND

Decomposition

Decomposition is a continuous, complex, and highly variable process which makes PMI estimations difficult. Immediately after death the cells undergo autolysis, which is initially caused by lack of oxygen, increase in carbon dioxide, and decrease in pH in cells (Gill-King 1997; Love and Marks 2003). Eventually, the cells will detach from each other and breakdown due to the accumulation of cellular enzymes, releasing fluid that will drive indigenous bacteria growth in the next stage of decomposition (ie., putrefaction) (Gill-King 1997). While there are no visible signs of the initial progression of autolysis, later signs include skin slippage and fluid filled blisters (Clark et al. 1997; Love and Marks 2003).

Additionally, the body undergoes a series of changes due to chemical and physical processes known as algor mortis, livor mortis, and rigor mortis that occur sequentially within the first day (Clark et al. 1997; Gill-King 1997; Love and Marks 2003). Algor mortis occurs when the body ceases to regulate its temperature and begins to reach ambient temperature, usually within 24 hours after death. In most cases this involves cooling of the body (Clark et al. 1997; Gill-King 1997; DiMiao and DiMiao 2001; Love and Marks 2003). Livor mortis or lividity occurs when the blood in the body begins to settle due to gravity to the lowest areas of the body and results in discoloration of the skin between two to eight hours after death (Clark et al. 1997; Gill-King 1997; DiMiao and DiMiao 2001; Love and Marks 2003). Rigor mortis is a chemical reaction

that causes the muscles in the body to stiffen. Rigor usually begins within a few hours after death and peaks at around 12 hours after death (Clark et al. 1997; Gill-King 1997; DiMiao and DiMiao 2001; Love and Marks 2003).

The next process of decomposition is putrefaction. During putrefaction micro-organisms (mainly bacteria) start to break down the soft tissue of the body which results in the formation of gases and liquids in the body (Clark et al. 1997; Gill-King 1997; DiMiao and DiMiao 2001; Love and Marks 2003). Green discoloration of the skin is one of the first signs of putrefaction, followed by bloating of the entire body (especially the abdomen) due to the buildup of gases (Clark et al. 1997; Gill-King 1997; DiMiao and DiMiao 2001; Love and Marks 2003). The pressure of the gases is released as purge fluid which exits all orifices (especially of the face) and any rips in the skin caused by bloating (Clark et al. 1997; Gill-King 1997; DiMiao and DiMiao 2001; Love and Marks 2003). These two processes alone can completely skeletonize a body, however, environmental factors and scavenger activity usually alters the time frame (Clark et al. 1997; Gill-King 1997; Love and Marks 2003).

Variables Affecting Decomposition

There are many variables that occur within the decomposition process that can increase or decrease the rate of decomposition. It is important to study these variables to gain a better understanding of the decomposition process and to make better postmortem interval estimations. Some of these variables include temperature, access of the body to insects, and moisture.

Temperature

Temperature has the greatest effect on the rate of human decomposition. In general, low temperatures reduce the rate of decomposition by retarding the chemical reactions of autolysis, the growth of bacteria associated with putrefaction, and the colonization and development of necrophagous insects (Mann et al. 1990; Galloway 1997; Campobasso et al. 2001). Conversely, warmer temperatures increase the rate of autolysis, bacterial growth, and insect activity which speeds up the decomposition process (Mann et al. 1990; Campobasso et al. 2001; Shirley et al. 2011).

Moisture

Moisture has also been found to have an effect on the rate of human decomposition. Moisture is necessary to avoid desiccation which will ultimately effect fly and maggot activity (Zhou and Byard 2011). In dry environments the body can quickly become desiccated or mummified resulting in almost complete preservation of skin with minimal insect activity (Mann et al. 1990; Galloway 1997). In wet environments, however, saponification can result in the formation of adipocere or grave wax due to the hydrolysis of fatty tissues (Gill-King 1997).

Access of the Body to Insects

Insects play a crucial role in rate of human decomposition, especially in an outdoor setting. The amount of insect activity can depend on the season of death. There is a decrease in insect species in the fall and winter seasons due to the colder weather, while there is an increase in insect species during the spring and summer seasons due to the warmer weather (Campobasso et al. 2001; Schroeder et al. 2003). Necrophagous fly larvae are primarily responsible for the loss of soft tissue during decomposition in an

outdoor setting, but numerous other insects also play a role (Haskell et al. 1997). For example, beetles, bees, ants, spiders, and cockroaches are all known to frequent decomposing bodies (Haskell et al. 1997). Ants are rarely given a second thought when found on or near human remains, but they are found at all stages of decomposition (Campobasso et al. 2009). Ants mainly prey on eggs, larvae of other insects and scavenge human flesh (Campobasso et al. 2009). If the ant population is large enough the rate of decomposition can be significantly reduced which will alter the PMI estimation (Catts and Goff 1992; Campobasso et al. 2009). In some cases, ant bites may be mistaken for antemortem abrasions or trauma (Keh 1985; Campobasso et al. 2009).

Insect activity can be greatly affected by different disposal areas. Various coverings such as clothing, blankets, and tarps provide protection for insects and especially larvae against the natural elements of wind, rain, predators and solar radiation (Mann et al. 1990; Campobasso et al. 2001; Shirley et al. 2011; Voss et al. 2011). Additionally, coverings can create a micro-environment that includes more humidity and warmer temperatures which results in greater insect diversity and abundance. This micro-environment therefore increases the rate of decomposition (Anderson 2001; Voss et al. 2011). Also coverings may delay the rate of insect colonization which can alter the PMI estimate (Goff 1992). In circumstances where remains are sealed in refrigerators or plastic bags the decomposition process is delayed due to lack of insect activity (Mann et al. 1990). Additionally, remains that decompose within an indoor setting will have extremely limited access to insect activity and temperature will be based on air conditioning (heating or cooling) settings (Campobasso et al. 2001). Burials cause a slower rate of decomposition due to the cooler temperatures, limited access of carrion

insects, and body temperature of the remains are solely based on autolytic and putrefaction processes (Mann et al. 1990; Bass 1997; Campobasso et al. 2001).

Decomposition Scales

Staging scales of decomposition have been produced that describe the morphological changes occurring in the body due to autolysis, putrefaction, and finally the breakdown of the skeleton by chemical and mechanical forces. For example, Galloway et al. (1989) categorized the decomposition process into five major categories: fresh, early decomposition, advanced decomposition, skeletonization, and extreme decomposition. Bass (1997) outlined five stages and their associated time frame of occurrence: fresh (first day), fresh to bloated (first week), bloated to decay (first month), dry (first year), and bone breakdown (first decade). Clark et al. (1997) generated four categories and ten stages of the human decomposition process: putrid (stages 1-3), bloating (stages 4-6), destruction (stages 7-8), and skeleton (stages 9-10). While useful for providing a general description of the continuous processes occurring during decomposition and providing rough estimates of the PMI, the stage descriptions are difficult to quantify.

Accumulated Degree Days (ADD)

Accumulated degree-days measure biological processes the heat energy units that have accumulated in the body and are available for bacterial and fly growth and therefore are a better way of measuring decomposition than calendar days (Megyesi et al. 2005). Using the temperature data from the HOBO station, ADD was calculated daily by averaging the high and low daily temperatures. Decomposition slows down significantly at 0°C, so this was set as the minimum threshold (Megyesi et al. 2005).

Megyesi et al. (2005) Method

Megyesi and colleagues (2005) made the first attempt to quantify the stages of decomposition. One unique feature of the Megyesi et al. (2005) method is that investigators examine each of the three main regions of the body (head/neck, torso, and limbs) separately using a modification of the descriptions for Galloway et al.'s (1989) stages of decomposition. Megyesi et al. (2005) placed the descriptions of Galloway et al's (1989) first four stages (fresh, early decomposition, advanced decomposition, and skeletonization) into sequential order and applied a point or scoring system to each major description. For example, if the head and neck show no visible signs of decomposition the head and neck region is given a score of 1. If the head and neck exhibit morphological features of early decomposition the region is given a score between 2 to 6 points depending on which morphological characteristics are present (e.g., discoloration, bloating, or purging). If advanced decomposition is observed the head and neck receives between 7 and 9 points, while skeletonization of the region results in a score of 10 to 13 depending on the amount of bone exposure and whether it is dry or retains some grease. Once all three regions of the body have been scored, the points from each region are summed to give a total body score (TBS). The TBS is then used to calculate an estimation of ADD required for decomposition. The calculated ADD can then be compared retrospectively to local temperature data to give a date point estimate and range for the estimation of the postmortem interval.

Previous Studies with Covered Remains

Miller (2002) examined six human cadavers that were fully clothed during the study period (one year) and compared stages of decomposition and ADD calculations with six nude cadavers from previous research as controls at the Anthropological Research Facility (ARF) at the University of Tennessee, Knoxville. There were placements during winter and summer months and decomposition was scored using a staging scale I to IV (fresh, early decomposition, advanced decomposition, and skeletonization). Results from the study show that clothing slows the rate of decomposition during spring and summer, but during winter months clothing didn't significantly alter rate of decomposition.

Dautartas (2009) used six human cadavers in which two were wrapped in plastic tarps, two were wrapped in cotton thermal blankets, and two were unwrapped controls. All six bodies were placed at the same time at ARF in Knoxville to control environmental factors acting on them. The bodies remained wrapped for thirty days and temperature data was collected daily. Ambient temperature was taken twice daily to calculate ADD and temperature was taken daily from soil underneath each body. At the end of the thirty day period the bodies were uncovered and decomposition was scored using the Megyesi et al. (2005) TBS method. In addition, notes on decomposition (e.g., insect activity, scavenger activity, and other general notes) and photographs were taken for each individual. Using the daily temperatures during the study period, ADD was calculated for each individual, and TBS scores were plugged into the Megyesi et al. (2005) formula to get an ADD estimate. Dautartas (2009) found no statistically significant difference between treatment bodies and controls when looking at temperature. Also there was no

statistically significant difference between estimated ADD and actual ADD. However, rate of decomposition was noticeably different between the treatment and control bodies.

Voss et al. (2011) studied the effects of clothing using ten freshly killed pigs, divided evenly between two years. Each year three pigs were clothed and two were unclothed as controls. This study was conducted at a wildlife reserve south of Perth, Western Australia during autumn. The study results show that the presence of clothing prolonged advanced decomposition due to the moisture and abundance of insect activity.

Bell (2012) examined three pigs placed on the ground surface in which one was wrapped in cotton bed sheet, one in a black garbage bag, and one was left unwrapped as the control. This study was conducted at the Forensic Anthropology Research Facility (FARF) in San Marcos, Texas. All three pigs were placed at the same time to ensure that the same environmental factors were acting on them. The wrapped pigs were left unopened until the end of the study period (142 days). Ambient and internal temperature was recorded along with visual observations of decomposition occurring outside of the wrappings and photographs during the study period. The purpose of the study was to test the accuracy of several of the published postmortem interval formulae (e.g., Megyesi (2005), Vass (2011), and Schiel (2008)). Bell (2012) observed that the pig wrapped in the trash bag had the most accelerated decomposition rate followed by the sheet and both were faster than the control. Overall, Bell (2012) found the accuracy of the PMI estimation based on all of the formulae tested to be poor.

Finally, Phalen (2013) studied three human cadavers that were clothed throughout the study period (2 months) and cadavers used in previous research at FARF at Texas State University. The three placements occurred during the months of May and June. To

compare decomposition rates a modified staging scale of Galloway et al. (1989) was used which segmented the body into six regions. Her results show that clothing accelerates the overall process of decomposition and most likely prevents mummification from occurring.

These five previous studies on covered remains reveal that there is not a consensus on the decomposition process and the effects that coverings have on rate of decomposition. Additionally, two of these studies used pigs as substitutes for humans and have small sample sizes. The studies that use human cadavers have small sample sizes in which their statistics have lower confidence levels and higher margins of error. Another possible problem with small sample sizes and decomposition studies is that the results may be outliers. Furthermore, Miller (2002) and Phalen (2013) have contradictory results which may be due to different environments but since there are no validation studies it is difficult to determine why these studies had different results. Therefore, there is a need to conduct a more thorough study of the effect of coverings on the decomposition rate of human remains.

Chapter Summary

Decomposition of human remains is a continuous and complex process in which many researchers have divided into descriptive stages. Megyesi et al. (2005) method was the first to quantify these stages. Many factors such as temperature, moisture, insect activity, concealment wrappings, and many others can affect the rate of human decomposition in any environmental region. The limited studies that have examined the effect of clothing and wrappings on the rate of decomposition, have used small sample sizes or pig substitutes. The purpose of this study is to examine the difference in the rate

of decomposition between bodies wrapped in plastic tarps compared to unwrapped controls using a relatively large sample size. This study will significantly contribute to the estimation of the postmortem interval and have an impact on the forensic science community when tarps are used for body disposal.

II. METHODS

STUDY POPULATION AND SAMPLE SIZE

The study population consisted of twenty individuals donated to the Forensic Anthropology Center at Texas State (FACTS) and allowed to decompose at the FARF in a semi-shaded area. All individuals were placed on the ground, unclothed, in a supine position, and under a metal cage. The metal cages were used to control for any animal scavenging that would have altered decomposition rates. Ten individuals were wrapped in a new plastic tarp and ten were not covered. Most placements consisted of two individuals (one tarp wrapped and one unwrapped control) being placed on approximately the same date in the same area of FARF approximately 10 feet apart to reduce micro-environmental effects. Hereafter, all tarp-wrapped remains will be referred to as tarp remains and the unwrapped remains will be referred to as control remains. Sixteen of the donated bodies (10 tarp and 6 controls) were placed at FARF between April and August 2015. There were four instances where there was not a control and tarp individual available at the same time. In these cases, photographs and notes for donations placed on approximately the same date in 2014 were used as a control. The weather between 2014 and 2015 did not vary too much since ADD were reached around the same number of days. In addition, only individuals arriving at FACTS in a fresh stage were used in the study in order to effectively use TBS scoring and accurately monitor decompositional changes.

Tarp and control pairs of bodies were not controlled for sex, age, body weight or autopsy (Table 2.1). While these variables could affect decomposition rates, it is not possible to control for all of these variables in the current study. There were five

individuals that were autopsied and included in the study population. All autopsied individuals had a traditional "Y" thoracoadominal incisions. Autopsied individuals were permitted due to a previous study at FARF that found no significant difference in decompositional rates between autopsied and non-autopsied remains (Bates 2014; Bates and Wescott 2016). In addition, only individuals arriving at FACTS in a fresh stage were used in the study in order to effectively use TBS scoring and accurately monitor decompositional changes.

Table 2.1. Demographics of study population.

Donation	Sex	Age	Weight (lbs.)	Autopsied
D13-2015 (T#1)	M	49	200	N
D06-2015 (C#1)	M	93	189	N
D16-2015 (T#2)	M	95	153	N
D19-2014 (C#2)	F	77	120	N
D19-2015 (T#3)	M	65	238	N
D20-2015 (C#3)	M	74	107	N
D21-2015 (T#4)	F	63	118	N
D21-2014 (C#4)	F	23	305	Y
D26-2015 (T#5)	F	21	140	Y
D24-2014 (C#5)	M	70	189	N
D31-2015 (T#6)	F	55	180	Y
D29-2015 (C#6)	M	44	154	Y
D32-2015 (T#7)	F	73	184	N

Table 2.1 Continued.

D23-2015 (C#7)	M	69	160	N
D34-2015 (T#8)	F	79	204	N
D35-2015 (C#8)	F	69	158	N
D38-2015 (T#9)	F	77	218	N
D39-2015 (C#9)	M	85	119	Y
D41-2015 (T#10)	F	57	95	N
D38-2014 (C#10)	M	79	220	N

DATA COLLECTION

Treatment of Remains

The wrapping procedure consisted of the following steps: 1) the 10 ft X 12 ft tarp was unfolded completely and the body was placed in the middle of the tarp, 2) the top and bottom ends were folded over the head and legs, 3) one side was then folded over the individual towards the opposite side, and 4) the remaining side was folded across the person and tucked in underneath the body to seal the tarp (see Figure 2.1). All the tarps used in the study were the same color with gray on the outside and brown on the other inside. The tarp individuals remained enclosed in the tarp until the sampling periods of 500, 1000, 1500, 2000 ADD were reached, except in one case described below. During each sampling period the tarp remains were opened to allow for photography of the body, recording of decomposition scores or TBS, and noting observation about insect activity, the presence of moisture, or other decompositional variables described below.

There were two small deviations in the data collection process. For the first set of remains (1 tarp and 1 control), motion-sensitive cameras were mounted near the bodies to observe any scavenger activity occurring outside the cage. Cameras were not used to monitor the remaining set of remains. For the sixth set of remains, I collected total body scores (TBS) for the control body each day. Once the control body transitioned from one stage of decomposition to the next (e.g, fresh to early decomposition) the tarp individual was unwrapped to examine the stage of decomposition. While the tarp was open photographs, notes, and TBS were collected. Similar to all other sets, data were also collected at 500, 1000, 1500, and 2000 ADD for the sixth set. The purpose of this deviation was to document the stage of decomposition in the tarp body as the control body transitioned from one stage to the next.

The other nine tarp individuals remained unopened until they reached the first sampling period of 500 ADD. Five hundred ADD was chosen because previous research at FARF indicates that mummification occurs on average around 500 ADD during spring and summer months (Bates, 2014). Until this first sampling point, each tarp and corresponding control individual (when applicable) had notes, photos and temperature taken daily.

Figure 2.1: Tarp individual at placement.

Observational Data Collected

During each sampling period the TBS was recorded following the method provided by Megyesi et al. (2005). The head, torso, and limbs were scored independently and then summed to produce a total body score. See Tables 2.2, 2.3, and 2.4 for decomposition descriptions and scores for the head, torso, and limbs, respectively.

Table 2.2. Description of Megyesi et al. stages of decomposition and scoring rubric for the head and neck (Reproduced from Megyesi et al., 2005; Table 2).

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

Table 2.3. Description of Megyesi et al. stages of decomposition and scoring rubric for the trunk (Reproduced from Megyesi et al., 2005; Table 3).

Decomposition Stage	Description and scoring rubric
Fresh	1pt: Fresh, no discoloration
Early Decomposition	2pts: Pink-white appearance with skin slippage and marbling present. 3pts: Gray to green discoloration: some flesh still relatively fresh. 4pts: Bloating with green discoloration and purging of decompositional fluids. 5pts: Postbloating following release of the abdominal gases, with discoloration changing from green to black.
Advanced Decomposition	6pts: Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity. 7pts: Moist decomposition with bone exposure less than one half that of the area being scored. 8pts: Mummification with bone exposure of less than one half that of the area being scored.
Skeletonization	9pts: Bones with decomposed tissue, sometimes with body fluids and grease still present. 10pts: Bones with desiccated or mummified tissue covering less than one half of the area being scored. 11pts: Bones largely dry, but retaining some grease. 12pts: Dry bone.

Table 2.4. Description of Megyesi et al. stages of decomposition and scoring rubric for the limbs (Reproduced from Megyesi et al., 2005; Table 4).

Decomposition Stage	Description and scoring rubric
Fresh	1pt: Fresh, no discoloration
Early Decomposition	2pts: Pink-white appearance with skin slippage of hands and/or feet. 3pts: Gray to green discoloration; marbling; some flesh still relatively fresh. 4pts: Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities. 5pts: Brown to black discoloration, skin having a leathery appearance.
Advanced Decomposition	6pts: Moist decomposition with bone exposure less than one half that of the area being scored. 7pts: Mummification with bone exposure of less than one half that of the area being scored.
Skeletonization	8pts: Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining. 9pts: Bones largely dry, but retaining some grease. 10pts: Dry bone.

Additionally, the bodies were observed daily and extensive notes were recorded. For control individuals, notes involved recording the presence of any odor, insect activity (especially maggots and flies), and gross decomposition processes (e.g, bloat, skin discoloration, marbling, skin slip, active purge, desiccation/mummification, adipocere, tissue re-hydration/moisture, mold, scavenger activity and skeletonization). For covered individuals, notes were more limited but consisted of recording presence of any odor, insect activity, especially maggots and flies exiting the tarp, other insects, purge or liquefaction exiting the tarp at either end, and changes in tarp tightness due to stage of bloat. When the tarp body was opened additional information on the decomposition process was recorded.

Body Temperature

External body temperature data in degrees Celsius were collected daily using a Thermoworks EL-USB-2 data logger from the surface of the control individuals and internal tarp temperature of the tarp individuals which were taken from around the abdominal area daily until 500 ADD was reached. The purpose was to determine if there are significant differences in external body temperature and internal tarp temperature which may help explain any possible differences in decomposition rates. External body temperature and internal tarp temperature data for the first two bodies were recorded for a month in order to establish how many days/ADD of temperature data should be recorded for each set of remains. The control body reached ambient temperature around the 500 ADD sampling period. In addition, Bates (2014) found that bodies placed at FARF generally reached ambient temperature by two weeks. Therefore, the remaining individuals in the study had temperature data taken until 500 ADD was reached, and only

the temperature data from date of placement until 500 ADD was used for statistical analyses.

Body temperature for the control bodies was taken by placing the data logger probe on the external skin surface of the pelvic region. For tarp individuals, a small hole was made in the tarp near the abdomen area and the temperature probe was placed inside the tarp to record the internal temperature. The hole in the tarp was covered with adhesive tape between data collection points to prevent any additional access to the body by insects. The Thermoworks logger was also used to record the ambient temperature approximately 10 feet from the body. Temperature for both tarp and control individuals was recorded every day until 500 ADD was reached. The difference was calculated by subtracting internal tarp temperature from the ambient temperature and subtracting external body temperature from the ambient temperature which was used to calculate the amount of heat generated by the decomposition process.

Environmental Data and Accumulated Degree Days

Ambient temperature, wind speed, and precipitation recorded every 30 minutes by the HOBO MicroStation at FARF were collected throughout the study period. The temperature data was used to calculate ADD based on the daily ambient temperature recorded in Celsius by the HOBO station.

Estimation of ADD Using Megyesi et al. (2005)

The TBS recorded for each body at 500, 1000, 1500, and 2000 ADD was used in the equation provided by Megyesi et al. (2005) to calculate the estimated ADD for each individual. The equation provided by Megyesi et al. (2005) is $ADD = 10^{(0.002*TBS*TBS+1.81)} \pm 776.32$. Inaccuracy and bias were calculated to determine if the equation provided by

Megyesi et al. (2005) over or under estimates the known ADD of the individuals in the study. Bias was calculated as Σ(estimated ADD –actual ADD)/n), and the absolute value was used for inaccuracy.

STATISTICAL ANALYSES

After data collection, statistical analyses were applied to determine if there was a statistically significant difference between the rates of decomposition in tarp and control individuals. An alpha level (α-level) of 0.05 was used to set significance. First, f-tests were run comparing all tarp and control TBS scores for each sampling period to determine if there was equal or unequal variance. Once variance was determined the appropriate t-test was run comparing the TBS scores between tarp and control samples for all four sampling periods. These four t-tests were performed with the goal of comparing the rate of decomposition between tarp and control individuals.

Internal tarp temperature and external body temperature were recorded for each set of tarp and control remains, respectively, during the first 500 ADD. The difference was calculated by subtracting the internal tarp temperature from the ambient temperature as well as, subtracting the external body temperature from the ambient temperature this was done for each day temperature data was taken. T-tests were applied to determine if there was a significant difference when comparing the calculated differences between ambient temperature and both external body temperature for each control individual and internal tarp temperature for each tarp individual during the first 500 ADD. A α-level of 0.05 was used to set significance. Additionally, five analysis of covariance (ANCOVA) were applied to determine if there was a statistically significant difference in the slope of

the regression lines between the calculated differences of ambient and external body temperature or internal tarp temperature.

III. RESULTS

RATE OF DECOMPOSITION: TARP VS. CONTROL HUMAN REMAINS

The results of the four f-tests and t-tests performed using TBS scores to compare the decomposition rate of all tarp and control remains are presented in Table 3.1. The mean TBS scores can be found in Figure 3.1. The f-tests results show that the first two sampling periods had equal variances, therefore, t-tests assuming equal variances were used. The remaining two sampling periods had unequal variances and t-tests assuming unequal variances were used. The t-tests comparing TBS scores between tarp and control remains indicate there was a significant difference in the rate of decomposition at all four sample periods (see Appendix C for photos of all remains at each sampling period). In all four sampling periods the calculated TBS was greater for the tarp bodies than for the control bodies. Additionally, no pattern was apparent in how the tarp remains decomposed.

The deviation in data collection with the sixth set of remains reveals that there is a difference in decomposition pattern. The tarp body was opened twice before ADD reached 500 which was the normal first sampling period for all the other tarp individuals. The first opening occurred three days after placement when the control body transitioned to early decomposition. TBS was recorded for both individuals and the TBS score was higher for the control individual. Some observed differences in decomposition were discoloration was light brown all-over for the tarp individual and the control individual had mostly dark red discoloration with light brown discoloration in the legs. Also maggots were heavy only from the waist up especially the face and neck area of the control, while the tarp individual had heavy maggot activity all-over the body.

Additionally, the tarp individual had skin slippage throughout the entire body while the control individual had skin slippage only in the arms, groin and sides of abdomen. Lastly, the control individual was in full bloat and the tarp individual had no bloat occurring.

The second opening occurred eight days after placement when the control body transitioned to advanced decomposition. TBS was one point higher in the control individual. Some differences in decomposition were observed such as discoloration for the tarp individual was grey brown all-over while the control individual had red brown discoloration. Additionally, the control individual was ending bloat while the tarp individual was just beginning to end bloat. Also there was a mass of dead flies by the feet of the tarp individual during the first opening and the second opening had dead maggots within the tarp.

At the 500 sampling period the remains were visually different and the TBS agreed. The tarp individual had the higher TBS score. Additionally, there were some differences in decomposition such as more skeletonization, more insect activity, and more liquefaction was present while the control individual was starting to dessicate in the head and neck region with mild insect activity.

Due to the heavy amounts of insect activity, there was small animal scavengers and vultures that consumed the insects that escaped the confines of the cage. Also there was signs of the smaller scavengers getting inside the cages and partially opening the tarps to get to the maggots. The tarps were partially opened for less than a day until notes were taken the following day.

Table 3.1. t-test & f-test results comparing TBS scores of all tarp and control remains.

		f-test				t-test		
Sampling Period (ADD)	**N[1]**	**score**	**p-value[2]**	**Equal variances**	**Mean TBS[1]**	**t stat**	**df**	**p-value[2]**
500	10, 10	1.031	0.4817	Yes	24.1, 21.1	2.517	18	0.0215
1000	10, 10	0.376	0.0807	Yes	26.4, 21.8	5.633	18	<0.001
1500	10, 10	0.207	0.0140	No	26, 22.9	2.871	13	0.0131
2000	10, 10	0.182	0.0092	No	26.8, 23.8	3.281	12	0.00655

[1]Tarp, Control
[2]$\alpha = 0.05$

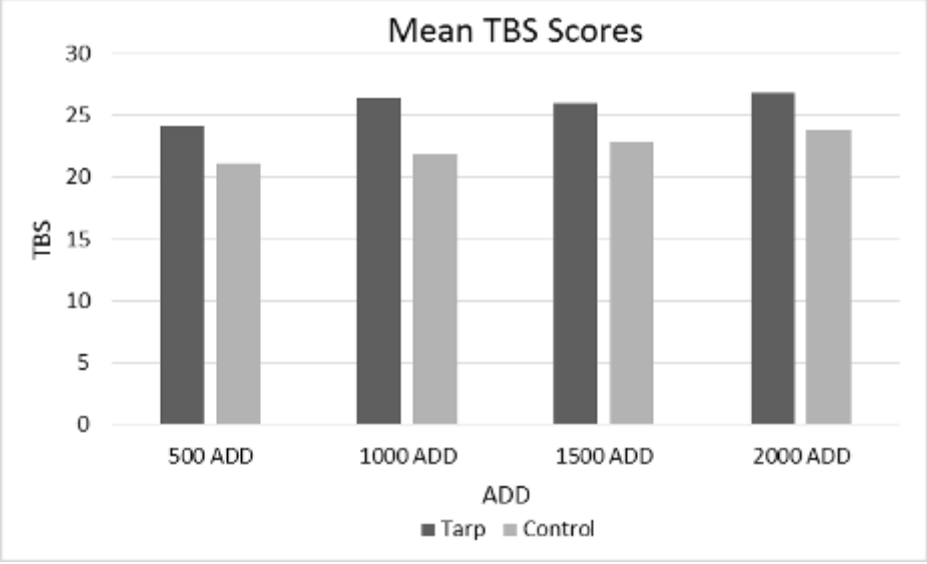

Figure 3.1: Mean TBS scores of tarp and control remains at each sampling period.

POSTMORTEM INTERVAL ESTIMATIONS USING MEGYESI ET AL. (2005)

The estimated ADD (Table 3.2) was calculated for each tarp and control individual using the recorded TBS score and formula $ADD = 10^{(0.002*TBS*TBS+1.81)} \pm 776.32$ provided by Megyesi et al. (2005). The estimated ADD of tarp and control individuals is compared at each sampling period (Figure 3.2-3.5). The total inaccuracy of the estimated ADD at each sampling point for tarp and control remains shows the inaccuracy is much higher for tarp individuals for the first two sampling periods (500 and 1000 ADD), but the last two sampling periods has greater inaccuracy for control individuals (Table 3.3; see Appendix A for complete data set). The results of the bias test show that the control remains have a positive bias (overestimates ADD) at 500 ADD but a negative bias (underestimates ADD) in all other sampling periods. The tarp remains, on the other hand, have a positive bias for all but the 2000 ADD sampling period.

Table 3.2: Estimated ADD based on TBS Scores.

Donations	500 ADD	1000 ADD	1500 ADD	2000 ADD
D13-2015 (T#1)	737.9042	737.9042	737.9042	1148.154
D06-2015 (C#1)	1148.154	1148.154	1452.112	1452.112
D16-2015 (T#2)	1148.154	1148.154	1148.154	1148.154
D19-2014 (C#2)	737.9042	737.9042	737.9042	916.2205
D19-2015 (T#3)	1853.532	1853.532	1853.532	3104.56
D20-2015 (C#3)	737.9042	1148.154	4073.803	4073.803
D21-2015 (T#4)	407.3803	1853.532	1853.532	1853.532
D21-2014 (C#4)	492.0395	492.0395	492.0395	492.0395
D26-2015 (T#5)	1148.154	1853.532	1853.532	1853.532
D24-2014 (C#5)	407.3803	492.0395	599.7911	916.2205
D31-2015 (T#6)	1853.532	1853.532	1853.532	1853.532
D29-2015 (C#6)	492.0395	492.0395	492.0395	737.9042
D32-2015 (T#7)	492.0395	1853.532	1148.154	1853.532
D23-2015 (C#7)	737.9042	737.9042	916.2205	916.2205
D34-2015 (T#8)	1148.154	1853.532	1148.154	1853.532
D35-2015 (C#8)	287.0781	287.0781	287.0781	599.7911
D38-2015 (T#9)	492.0395	1853.532	1853.532	1853.532
D39-2015 (C#9)	492.0395	492.0395	599.7911	737.9042
D41-2015 (T#10)	1853.532	1853.532	1853.532	1853.532
D38-2014 (C#10)	209.894	287.0781	407.3803	492.0395

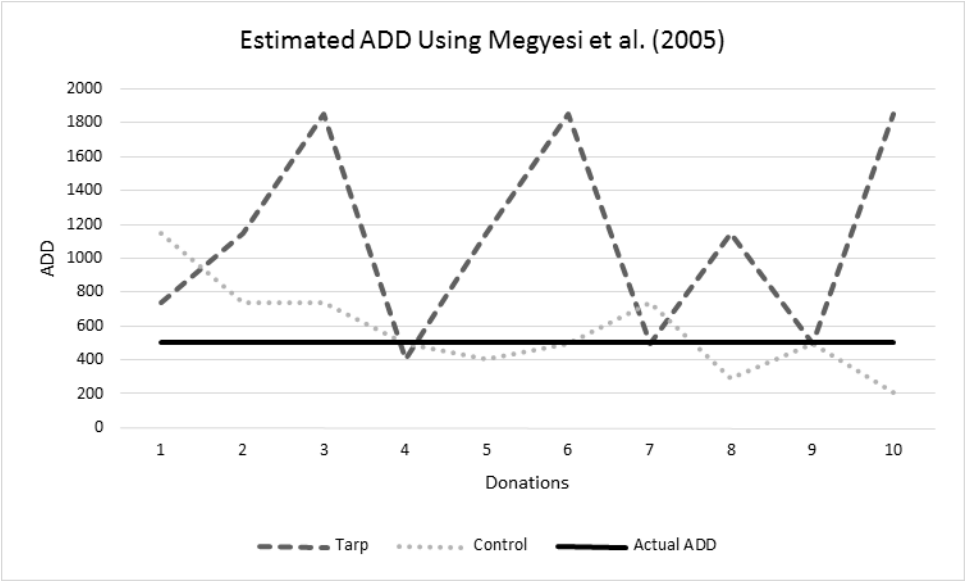

Figure 3.2: Estimated ADD of all tarp and control individuals at first sampling period (500 ADD) based on TBS scores.

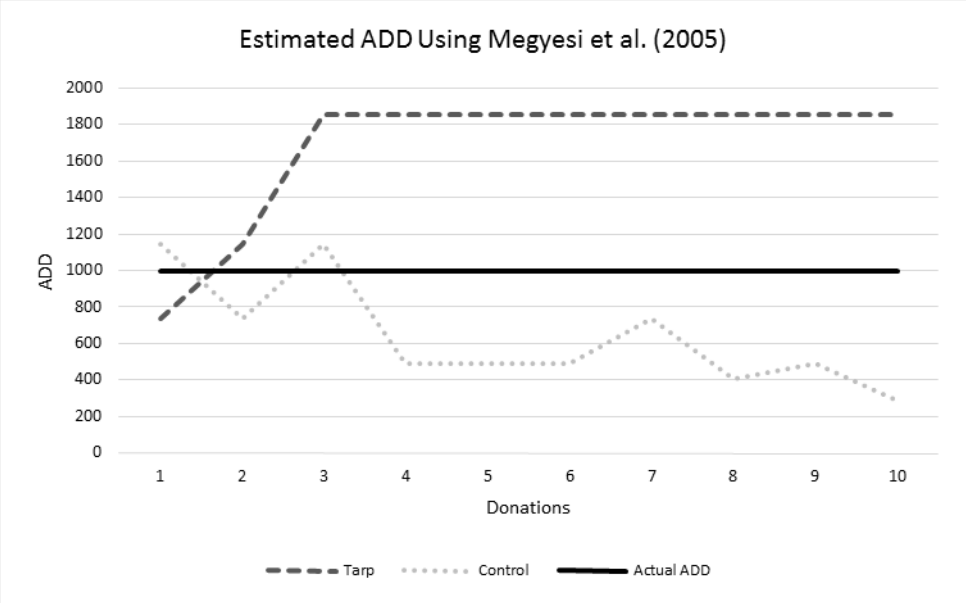

Figure 3.3: Estimated ADD of all tarp and control individuals at second sampling period (1000 ADD) based on TBS scores.

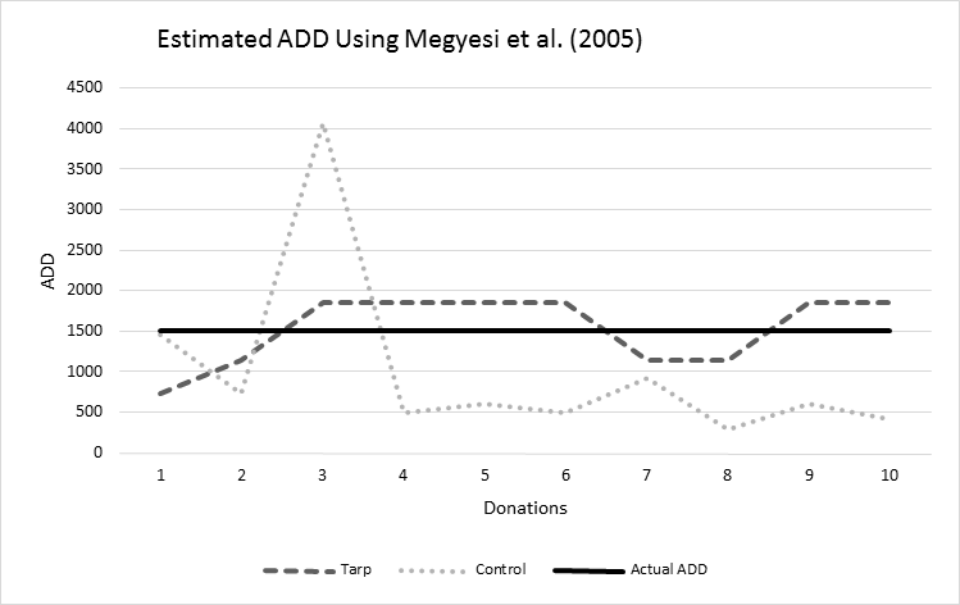

Figure 3.4: Estimated ADD of all tarp and control individuals at third sampling period (1500 ADD) based on TBS scores.

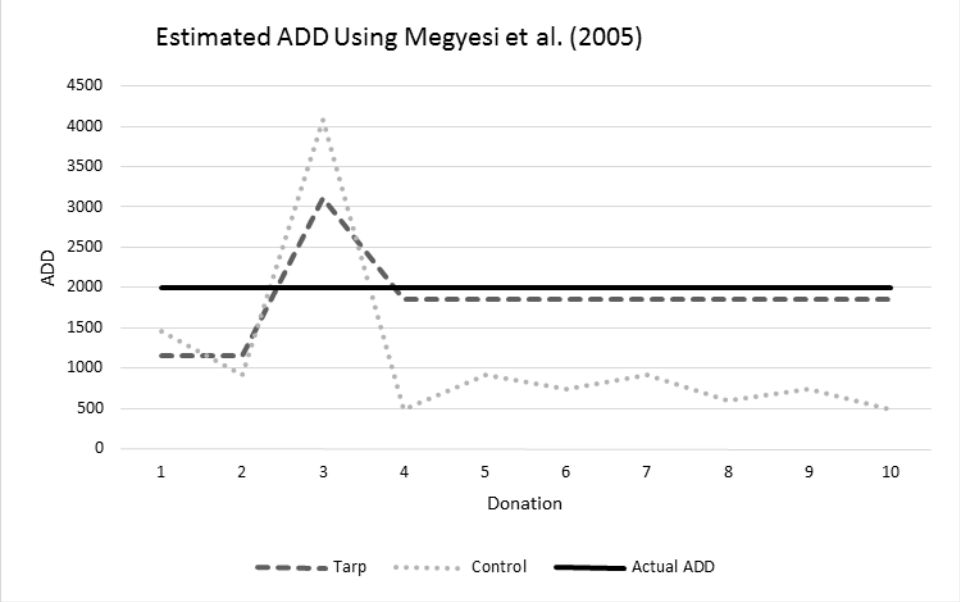

Figure 3.5: Estimated ADD of all tarp and control individuals at fourth sampling period (2000 ADD) based on TBS scores.

Table 3.3: Bias and inaccuracy of estimated ADD at the four sampling periods.

	Control		Tarp	
ADD	**Bias**	**Inaccuracy**	**Bias**	**Inaccuracy**
500	74	198	613	635
1000	-356	415	671	723
1500	-494	1008	30	393
2000	-866	1281	-162	383

TEMPERATURE: TARP VS. CONTROL

The results of the five f-tests and t-tests performed compared the difference between ambient temperature and both external body temperature for each control individual and internal tarp temperature for each tarp individual during the first 500 ADD are presented in Table 3.4. Both equal and unequal t-tests were used based on the results of the variance test. Two t-tests showed that there was a significant difference when comparing the differences in temperature between two sets of tarp and control individuals (Figure 3.6 and 3.7), while there were not significant differences for the other three sets of remains (Figure 3.8-3.10). In the two comparisons that were significant the temperature was greater inside the tarp compared to the external skin temperature of the controls during most of the sampling period.

The results of five analysis of covariance (ANCOVA) performed using the difference between ambient and both external body temperature for each control and internal tarp temperature for each tarp for the first 500 ADD are presented in Table 3.5.

The results showed that only D19-2015 (Tarp#3) and D20-2015 (Control #3) had a significant difference in the slope of the regression lines while the other four were not significantly different (Table 3.5, Figure 3.6). The difference in this case was caused by a high spike in temperature inside the tarp from days 7 to 15.

Table 3.4: Results of t-tests and f-tests comparing difference between ambient temperature and both external body temperature of controls and internal body temperature of tarp remains.

		f-test			t-test		
Donations	**N[1]**	**score**	**p-value[2]**	**Equal variances**	**t stat**	**df**	**p-value[2]**
D13-2015 (T#1) & D06-2015 (C#1)	23,23	2.67	0.012	No	1.35	36	0.18
D19-2015 (T#3) & D20-2015 (C#3)	20,20	10.81	<0.001	No	3.31	22	0.0031
D31-2015 (T#6) & D29-2015 (C#6)	17,17	5.75	0.00055	No	3.02	21	0.0064
D34-2015 (T#8) & D35-2015 (C#8)	17,17	1.71	0.146	Yes	0.97	32	0.33
D38-2015 (T#9) & D39-2015 (C#9)	16,16	2.317	0.057	Yes	-0.46	30	0.642

[1]Internal tarp temperature, External body temperature
[2]$\alpha = 0.05$

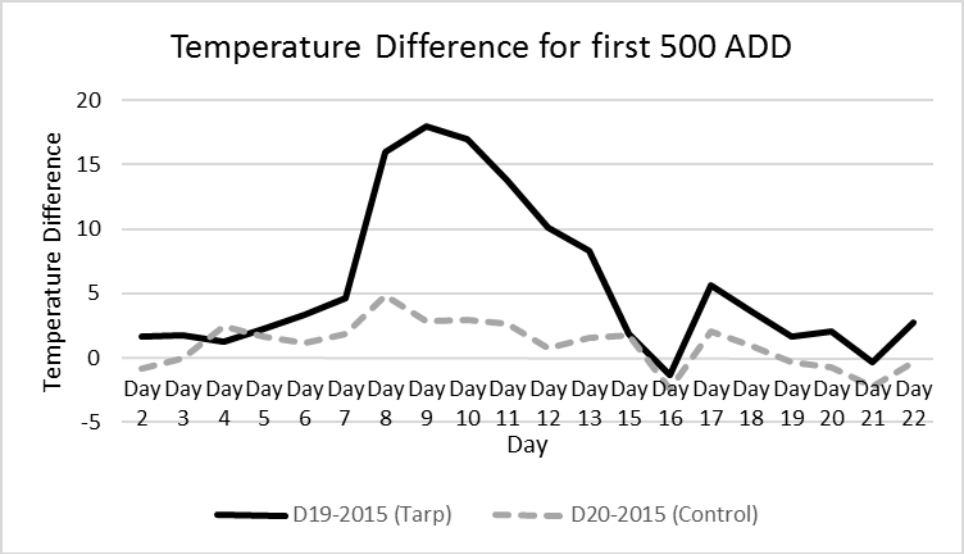

Figure 3.6: Temperature difference between ambient temperature and both external body temperature of D20-2015 (C#3) and internal tarp temperature of D19-2015 (T#3).

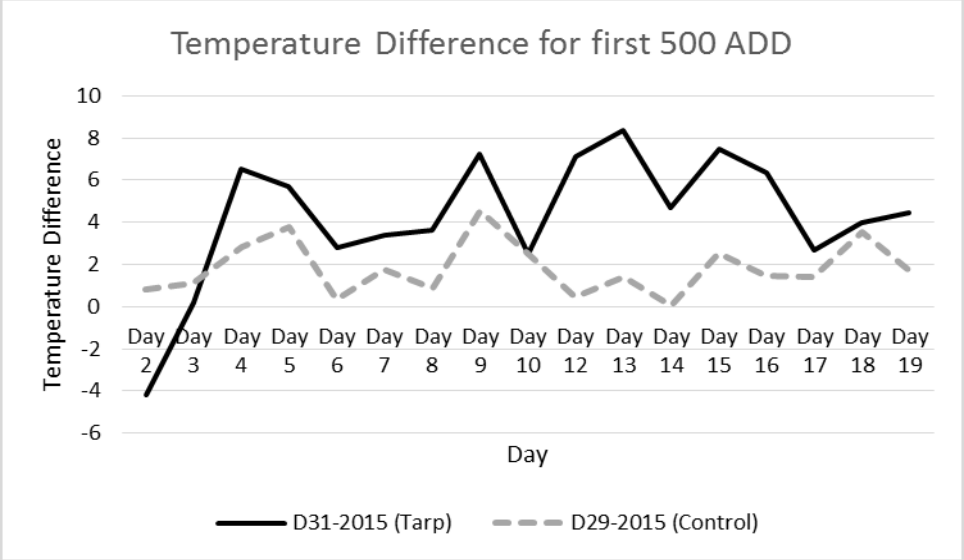

Figure 3.7: Temperature difference between ambient temperature and both external body temperature of D29-2015 (C#6) and internal tarp temperature of D31-2015 (T#6).

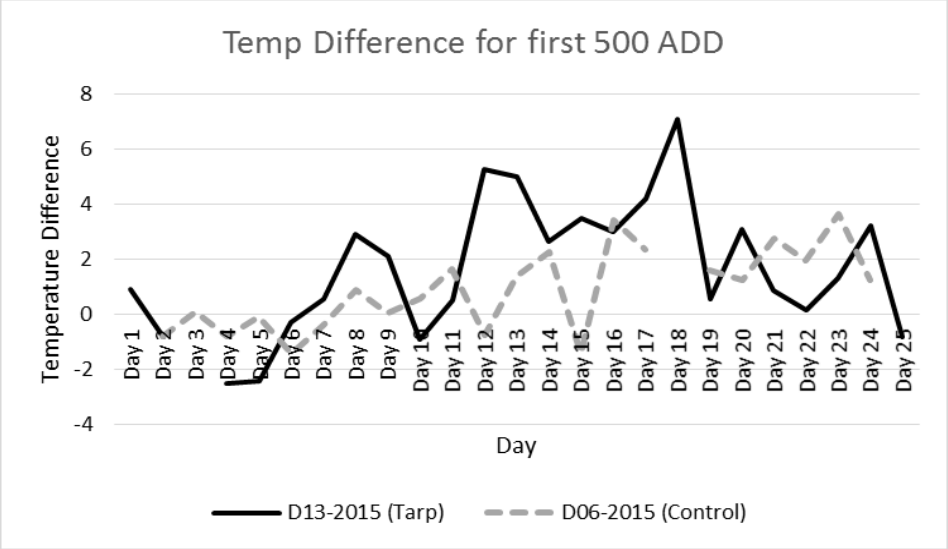

Figure 3.8: Temperature difference between ambient temperature and both external body temperature D06-2015 (C#1) and internal tarp temperature of D13-2015 (T#1).

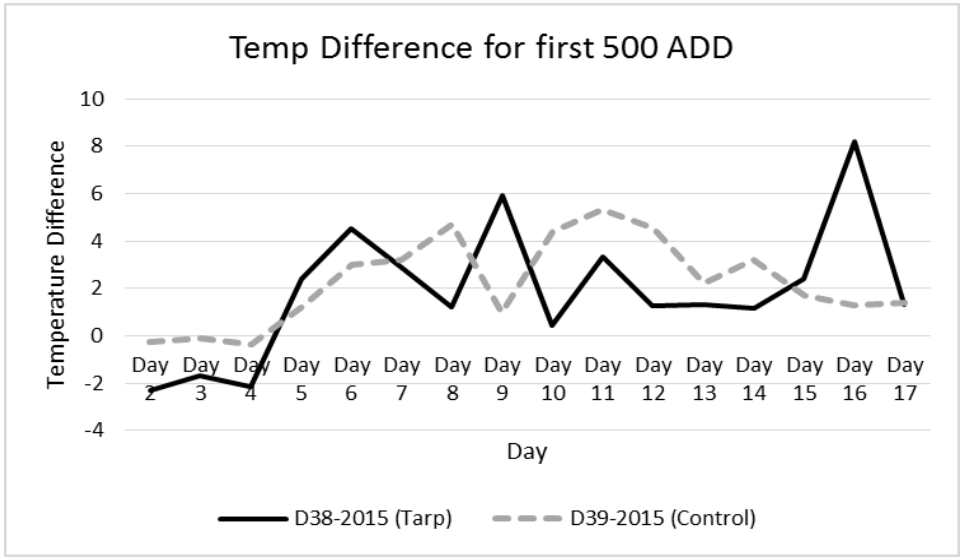

Figure 3.9: Temperature difference between ambient temperature and both external body temperature D39-2015 (C#9) and internal tarp temperature of D38-2015 (T#9).

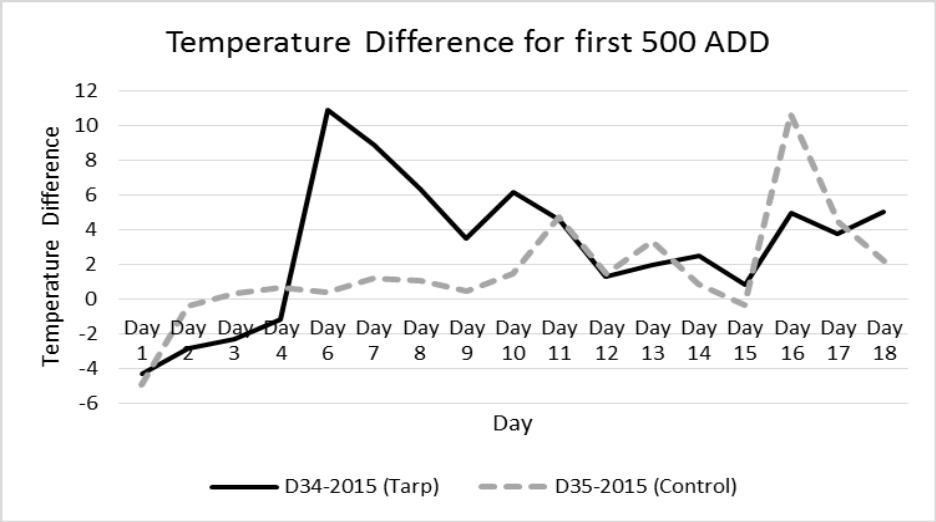

Figure 3.10: Temperature difference between ambient temperature and both external body temperature D35-2015 (C#8) and internal tarp temperature of D34-2015 (T#8).

Table 3.5: Analysis of covariance (ANCOVA) comparing difference between ambient temperature and both external body temperature of control remains and internal tarp temperature of tarp remains.

Donations	SS	df	MS	F	p-value[1]
D13-2015 (T#1) & D06-2015 (C#1)	47686.07	1	47686.07	0.7785	0.388
D19-2015 (T#3) & D20-2015 (C#3)	3803728	1	3803728	22.244	0.000172
D31-2015 (T#6) & D29-2015 (C#6)	170395.6	1	170395.6	1.8911	0.189
D34-2015 (T#8) & D35-2015 (C#8)	201712.6	1	201712.6	1.206	0.289
D38-2015 (T#9) & D39-2015 (C#9)	64195.63	1	64195.63	0.805	0.384

[1] $\alpha = 0.05$

IV. DISCUSSION AND CONCLUSION

Plastic tarps are commonly used to conceal and dispose of deceased humans due to criminal activities (Forbes et al., 2009; Komar, 2003; Manhein, 1997). Therefore, it is important to understand the effects of wrapping a body in a plastic tarp has on the rate of human decomposition. Most previous studies examining the decomposition process of human remains have been conducted on bodies placed uncovered on the ground surface. There has been minimal research on the effects of wrapping on the rate of human decomposition. The previous studies that have examined differences in the decomposition rate between covered and uncovered bodies have either used animal remains as human substitutes (Bell 2013; Shattuck 2009; Hyder 2007; Goff 1992; Kelly et al. 2009; Voss et al. 2011; Matuszewski et al. 2014) or the sample size has been extremely small (Cahoon 1992; Goff 1992; Miller 2002; Dautartas 2009; Phalen 2013). Therefore, this study was undertaken to compare the difference in decomposition between tarp and control bodies using a relatively large sample of human remains with known postmortem intervals.

RATE OF DECOMPOSITION: TARP VS. CONTROL HUMAN REMAINS

This study showed that wrapped human remains in plastic tarps has a statistically significant effect on the rate of human decomposition as measured by TBS when compared to remains in a Central Texas environment. The tarp bodies decomposed significantly faster than the uncovered bodies. The deviation in the data collection revealed that in this instance the control body was decomposing faster (as measured by TBS) earlier on and at the 500 ADD sampling period the tarp remains were decomposing faster. This result may be due to a delay in insect activity and less liquefaction within the

tarp but further studies of this earlier period needs to be examined. Bass (1997) observed that a fleshed body can become skeletonized rapidly due to certain environmental conditions such as high temperatures, humidity, heavy insect activity, and shade from direct sunlight. Therefore, this study examined the role of temperature in the differences in decomposition rates.

According to the five t-tests performed, temperature was significantly different in only two sets of remains, while the other three sets of remains had non-significant differences in temperature. These results show that temperature may contribute to the difference observed in rate of decomposition between tarp and control individuals, but temperature is unlikely the primary factor for the different rates of decomposition observed between the control and tarp bodies. One reason that temperature may not have played a dominate role in this study was that, all of the remains that had temperature data taken were placed in a semi-shaded area of FARF which could have contributed to both tarp and control remains having similar temperatures. Alternatively, had these remains been placed in an open area with direct sunlight for majority of the day the temperature may have been significantly different due to the tarps ability to retain heat. However, it should be noted that Dautartus (2009) also found no significant temperature difference between tarp and control bodies. While Bell (2013) also found fairly consistent temperatures between all three pigs.

The difference in decomposition between tarp and control bodies then is most likely due to an increase in moisture and insect activity within the tarp. No quantifiable test for moisture content and insect activity was used in this study, but previously

researchers has observed that retaining of moisture and increased insect activity usually skeletonizes remains at a much quicker rate (Galloway 1997).

MOISTURE

While moisture was not quantified in this study, extensive notes were taken that can provide some information about the role of moisture in the decomposition process. At each sampling point, the tarp remains always had moist decompositional fluid and liquefied tissue within the bottom of the tarp which kept the remains moist (see photos in Appendix C). Fluid loss occurred at the head or foot regions of the tarp. This process subsequently immerses the body in moist decompositional fluid which allows advanced decomposition especially maggot activity to occur for a longer period of time compared to the control surface decomposition, which became desiccated (Haskell et al. 1997; Kelly et al. 2009; Zhou and Byard 2011).

Hyder (2007) examined the decomposition process of nine pigs enclosed in separate sealed containers. The results show that the rate of decomposition was significantly slower than the control. The key variable that caused this difference was lack of insect activity due to the enclosed container. Only three of the nine containers had insect activity and most of the maggots were dead due to heat or lack of air. Another factor was the humid micro-environment that was created within the container. Temperature data collected within the containers shows that it maintained a steady difference from the ambient temperature throughout the summer months. The humidity prevented mummification from occurring while the control mummified which caused prolonged advanced decomposition. Hyder (2007) concluded that the enclosed micro-

environment caused early decomposition to have a slower rate while skeletonization was accelerated.

Temperature and moisture are both contributing factors with regards to rate of decomposition within this study since insect activity was dependent on both of these factors. As Hyder (2007) showed humidity was present as well as higher temperatures but rate of decomposition was slower since insect activity was controlled for. This is further evidence that these two variables are contributing and not causal factors in the rate of decomposition in this study.

INSECTS

Previous research on wrapped or covered remains shows that plastic tarps provides a protective, warm, humid and shaded environment which creates greater insect activity (Anderson 2001; Kelly et al. 2009; Shirley et al., 2011; Clark et al., 1997; Voss 2011). Additionally, if remains are uncovered the maggots will leave the skin alone and only feed on the inside of the body so that the skin is left as a barrier from the sun (Bass 1997). Certain compounds and environments such as ammonia, hydrogen sulphide, pheromones and moisture are important stimulates for oviposition (Anderson 2001; Amendt et al. 2004). Successful development of eggs and larvae require moisture therefore, oviposition does not occur in dehydrated or mummified tissue (Amendt et al. 2004). Blow flies are diurnal species which means that they do not ovipost at night, however, they will often ovipost in dark areas such as under wrappings, in containers and dark basements during the daytime (Anderson 2001). Additionally, survival of early instar larvae is dependent on liquid protein, so as decompositional fluids accumulate within the tarp more sites of oviposition are created which result in larger maggot masses,

therefore, decomposition occurs at faster rates (Smith 1986; Anderson 2001). During each sampling period of this study a greater amount of insect larvae was observed associated with the tarp bodies compared to the control bodies. Also insect activity for the tarp remains persisted throughout the entire study but as the control remains became desiccated the insect activity consisted of beetles and ants only. Both tarp and control remains had similar insect colonization that consisted of blow fly larvae, soldier fly larvae, variety of beetles, and ants. During summer months the temperatures can also exceed the upper threshold limits of insect larvae causing a delay in their development (Kelley et al. 2009). During sampling periods, dead maggots were observed in the tarp but there was still heavy insect activity. Predation on insects by scavengers occurred during the study period of both tarp and control remains which had little impact overall on number of colonizers (Anderson 2001).

OTHER FACTORS

It is possible that other factors such as differences in body mass could have contributed to the difference in the rate of decomposition between the tarp and control remains. As Table 2.1 shows the ages range from 21 to 95 with an average age of 65. Also males and females were split evenly with ten each. There are two instances where the tarp body has a much bigger body mass than the control, however, there are two instances where the control body has a much bigger body mass than the tarp body. The other six pairs have relatively similar body masses. These factors were not controlled for since it would have limited the sample size and extended the data collection period.

ESTIMATION OF ADD USING MEGYESI ET AL. (2005)

Megyesi et al. (2005) method was used to compare decomposition rates and estimate ADD in this study. The TBS scores for every individual was used to estimate the ADD required at each sampling period. The results of the bias test show that the control remains have a positive bias (overestimates ADD) at 500 ADD but a negative bias (underestimates ADD) in all other sampling periods. The tarp remains, on the other hand, have a positive bias for all but the 2000 ADD sampling period. That is, in Central Texas fewer ADD were required to reach the observed TBS for the tarp individuals than was predicted by the Megyesi et al. (2005) equation, while more ADD was required to reach the observed TBS for the control bodies. The inaccuracy is much higher for tarp individuals at ADD 500 and ADD 1000. However, at ADD 1500 and 2000 there was greater inaccuracy for the control individuals. These results demonstrate that the current Megyesi et al. (2005) equations do not accurately estimate ADD when remains are wrapped or covered, therefore, new methods specifically designed for wrapped or covered remains need to be created or an adjustment needs to be made to the current Megyesi et al. (2005) equation. These results support previous studies that have been conducted in the Central Texas area testing the validity of using TBS for PMI estimation on surface human decomposition (Suckling 2011; Duecker and Mavroudas 2014). Additionally, Parks (2011) found the estimation given by Megyesi et al. (2005) to be consistent with the actual ADD, however, the sample size was one individual in a Central Texas environment. However, Dautartas (2009) found there to be no statistically significant difference but a marked difference was shown between estimated ADD and known ADD.

This was the first large scale study to examine the validity of TBS and ADD on wrapped or covered remains in a Central Texas environment. These results show that the Megyesi et al. (2005) method may only work in certain environments due to the significant variables that the decomposition scoring system did not specifically address. Even ADD estimations of the control remains were inaccurate suggesting that this method needs updating by adjusting the TBS values and definitions to reflect the decomposition that occurs in a Central Texas environment. Additionally, some of the decompositional changes that occurred with remains within the tarp and control remains did not fit the descriptions defined in Megyesi et al. (2005) very well. This was due to the descriptions being very specific and not taking desiccation into account for each body region. For example, some of the descriptions have specific discoloration (e.g., green and brown) when discoloration is variable (Suckling 2011; Sears 2013). Additionally, within the article it states that limbs do not bloat or purge fluid which is inaccurate and can have an effect on the decomposition process (Suckling 2011). Lastly, some of the descriptions are not in sequential order that decomposition occurs in Central Texas, for example, under advanced decomposition moist decomposition with bone exposure is followed by mummification with bone exposure and desiccation is not an option until the skeletonization category (Suckling 2011; Sears 2013).

CONCLUSION

Understanding how decomposition rates of tarp and control remains differ is crucial to PMI estimations which greatly impacts the forensic science community. Currently, there is no decompositional staging scale or method of estimating PMI of wrapped or covered remains. This is due to lack of research with ample sample sizes and

using animal substitutes instead of human remains. This study is of use in estimating PMI because it has a relatively large sample size and it uses human remains. Additionally, this study will contribute to the field of forensic anthropology by providing reliable information about the effect wrapping bodies in plastic tarp material has on the decomposition rate in Central Texas. This study adds to the forensic anthropological literature that has invalidated the Megyesi et al. (2005) as a means to estimate PMI in a Central Texas environment (Suckling 2011; Duecker and Mavroudas 2014). Law enforcement and other forensic scientists should be very cautious if using the Megyesi et al. (2005) method and be fully aware of its limitations and inconsistent results. PMI estimations in general are very hard to estimate and usually have very wide ranges since there are so many variables (e.g., environment, micro-environment, temperature, insect activity, scavengers, humidity, and solar radiation) that you have to take into account that can effect decomposition.

The primary null hypothesis of this study was that tarp remains would have no statistically significant effect on the rate of human decomposition when compared to control remains. The primary null hypothesis was rejected, so temperature was examined to see if it contributed to the change in the decomposition rate. Temperature was found to be only significantly different in two of the five tests so temperature does not appear to be the primary contributing factor but may still be playing a role since the temperature inside the tarp was generally a few degrees higher than on the external surface of the control bodies. Most of the difference is likely due to increased insect activity associated with the tarp bodies. Because the tarp retains moisture and protects the insect larvae from

direct sunlight and predators while creating an ideal humid and shaded environment for the insect larvae to thrive.

FUTURE RESEARCH

While this study has increased our understanding of the effect of tarps on the rate of human decomposition, the primary causal factors are still widely unknown. This study found a significant difference between tarp and control remains while a previous study with a much smaller sample size in a different environment found no significant difference in decomposition rates. The difference in results from this study and previous studies makes it clear that more studies need to occur to validate these results and examine what happens in other untested environments. Additionally, this study was conducted during the summer months and it would be of great interest to perform this study during winter months in Central Texas. Furthermore, a more in-depth study that could be of interest is the effect of plastic tarps on rate of decomposition when remains are wrapped and then buried. Additionally, the inaccurate results of PMI estimation using TBS shows that new formulae for a Central Texas environment needs to be created not only for wrapped or covered bodies but for control bodies as well.

APPENDIX SECTION

APPENDIX A: BIAS OF ADD ESTIMATES USING MEGYESI ET AL. (2005)

Donation	500 ADD	1000 ADD	1500 ADD	2000 ADD
D13-2015 (T#1)	237.90	-262.09	-762.09	-851.84
D06-2015 (C#1)	648.15	148.15	-47.88	-547.88
D16-2015 (T#2)	648.15	148.153	-351.84	-851.84
D19-2014 (C#2)	237.90	-262.09	-762.09	-1083.77
D19-2015 (T#3)	1353.53	853.53	353.53	1104.56
D20-2015 (C#3)	237.90	148.15	2573.80	2073.80
D21-2015 (T#4)	-92.61	853.53	353.53	-146.46
D21-2014 (C#4)	-7.96	-507.96	-1007.96	-1507.96
D26-2015 (T#5)	648.15	853.53	353.53	-146.46
D24-2014 (C#5)	-92.61	-507.96	-900.20	-1083.77
D31-2015 (T#6)	1353.53	853.53	353.53	-146.46
D29-2015 (C#6)	-7.96	-507.96	-1007.96	-1262.09
D32-2015 (T#7)	-7.96	853.53	-351.84	-146.46
D23-2015 (C#7)	237.90	-262.09	-583.77	-1083.77
D34-2015 (T#8)	648.15	853.53	-351.84	-146.46
D35-2015 (C#8)	-212.92	-592.62	-1212.92	-1400.20
D38-2015 (T#9)	-7.96	853.53	353.53	-146.46
D39-2015 (C#9)	-7.96	507.96	-900.20	-1262.09
D41-2015 (T#10)	1353.53	853.53	353.53	-146.46
D38-2014 (C#10)	-290.10	-712.92	-1092.61	-1507.96

APPENDIX B: INACCURACY OF ADD ESTIMATES USING MEGYESI ET AL. (2005)

Donation	500 ADD	1000 ADD	1500 ADD	2000 ADD
D13-2015 (T#1)	237.90	262.09	762.09	851.84
D06-2015 (C#1)	648.15	148.15	47.88	547.88
D16-2015 (T#2)	648.15	148.15	351.84	851.84
D19-2014 (C#2)	237.90	262.09	762.09	1083.77
D19-2015 (T#3)	1353.53	853.53	353.53	1104.56
D20-2015 (C#3)	237.90	148.15	2573.80	2073.80
D21-2015 (T#4)	92.61	853.53	353.53	146.46
D21-2014 (C#4)	7.96	507.96	1007.96	1507.96
D26-2015 (T#5)	648.15	853.53	353.53	146.46
D24-2014 (C#5)	92.61	507.96	900.20	1083.78
D31-2015 (T#6)	1353.53	853.53	353.53	146.46
D29-2015 (C#6)	7.96	507.96	1007.96	1262.09
D32-2015 (T#7)	7.96	853.53	351.84	146.46
D23-2015 (C#7)	237.90	262.09	583.77	1083.78
D34-2015 (T#8)	648.15	853.53	351.84	146.46
D35-2015 (C#8)	212.92	592.62	1212.92	1400.20
D38-2015 (T#9)	7.96	853.53	353.53	146.46
D39-2015 (C#9)	7.96	507.96	900.20	1262.09
D41-2015 (T#10)	1353.53	853.53	353.53	146.46
D38-2014 (C#10)	290.10	712.92	1092.62	1507.96

APPENDIX C: PHOTOS OF TARP AND CONTROL REMAINS AT EACH SAMPLING POINT

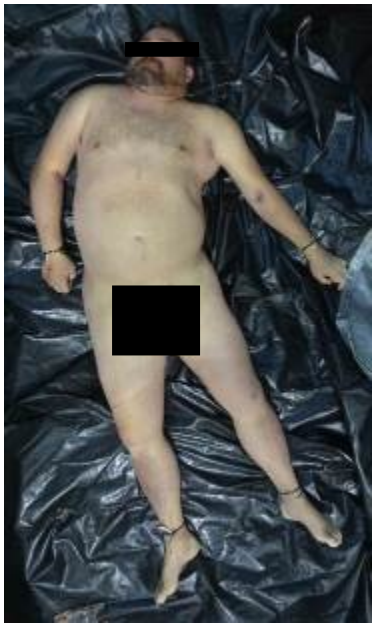

Figure C.1: D13-2015 (Tarp #1) at Placement

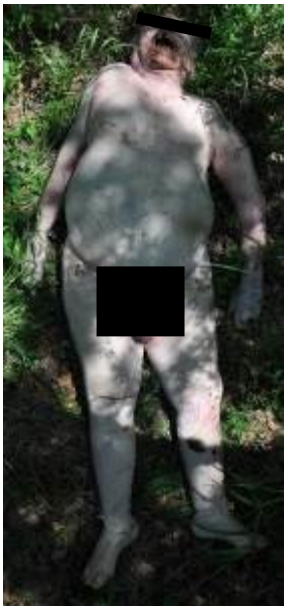

Figure C.2: D06-2015 (Control #1) at Placement

Figure C.3: D13-2015 (Tarp #1) at 500 ADD

Figure C.4: D06-2015 (Control #1) at 500 ADD

Figure C.5: D13-2015
(Tarp #1) at 1000 ADD

Figure C.6: D06-2015
(Control #1) at 1000 ADD

Figure C.7: D13-2015
(Tarp #1) at 1500 ADD

Figure C.8: D06-2015
(Control #1) at 1500 ADD

Figure C.9: D13-2015 (Tarp #1) at 2000 ADD

Figure C.10: D06-2015 (Control #1) at 2000 ADD

Figure C.11: D16-2015 (Tarp #2) at Placement

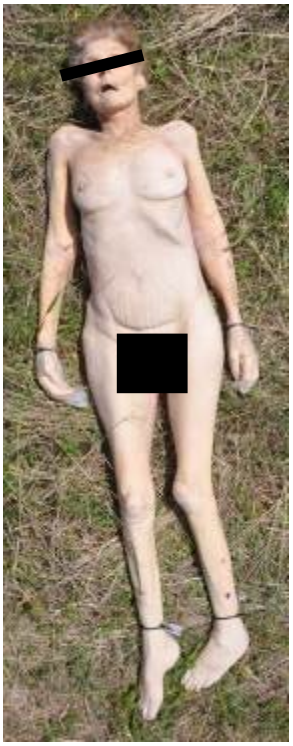

Figure C.12: D19-2014 (Control #2) at Placement

Figure C.13: D16-2015 (Tarp #2) at 500 ADD

Figure C.14: D19-2014 (Control #2) at 500 ADD

Figure C.15: D16-2015 (Tarp #2) at 1000 ADD

Figure C.16: D19-2014 (Control #2) at 1000 ADD

Figure C.17: D16-2015 (Tarp #2) at 2000 ADD

Figure C.18: D19-2014 (Control #2) at 2000 ADD

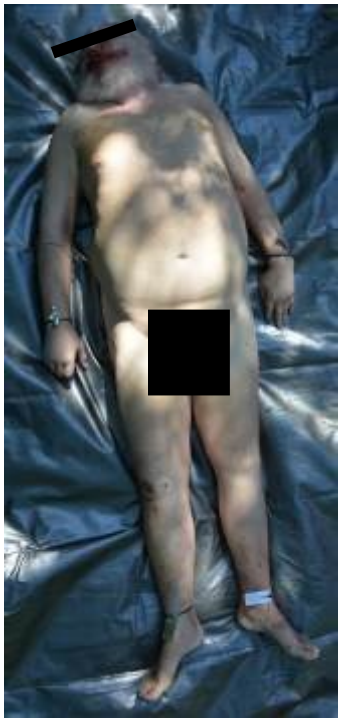

Figure C.19: D19-2015 (Tarp #3) at Placement

Figure C.20: D20-2015 (Control #3) at Placement

Figure C.21: D19-2015 (Tarp #3) at 500 ADD

Figure C.22: D20-2015 (Control #3) at 500 ADD

Figure C.23: D19-2015 (Tarp #3) at 1000 ADD

Figure C.24: D20-2015 (Control #3) at 1000 ADD

Figure C.25: D19-2015 (Tarp #3) at 1500 ADD

Figure C.26: D20-2015 (Control #3) at 1500 ADD

Figure C.27: D19-2015 (Tarp #3) at 2000 ADD

Figure C.28: D20-2015 (Control #3) at 2000 ADD

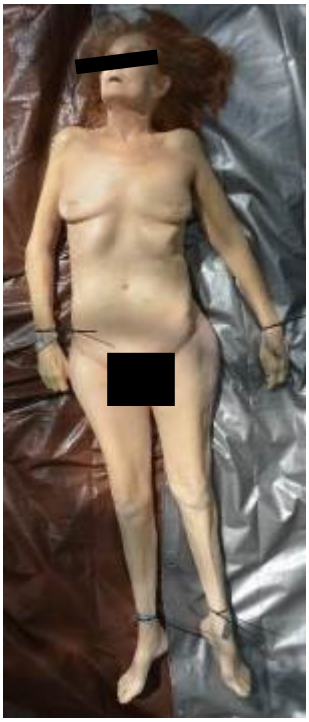

Figure C.29: D21-2015 (Tarp #4) at Placement

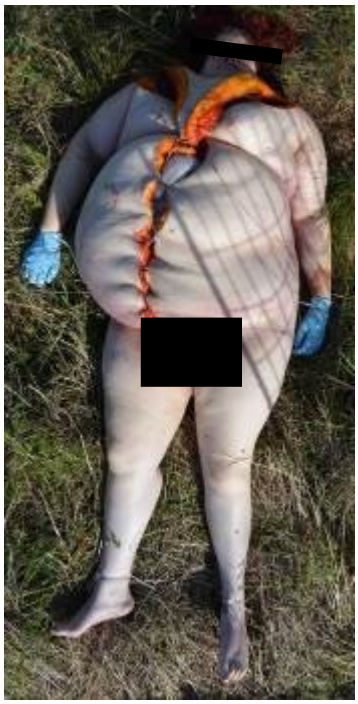

Figure C.30: D21-2014 (Control #4) at Placement

Figure C.31: D21-2015 (Tarp #4) at 500 ADD

Figure C.32: D21-2014 (Control #4) at 500 ADD

Figure C.33: D21-2015 (Tarp #4) at 1000 ADD

Figure C.34: D21-2014 (Control #4) at 1000 ADD

Figure C.35: D21-2015 (Tarp #4) at 1500 ADD

Figure C.36: D21-2014 (Control #4) at 1500 ADD

Figure C.37: D21-2015 (Tarp #4) at 2000 ADD

Figure C.38: D21-2014 (Control #4) at 2000 ADD

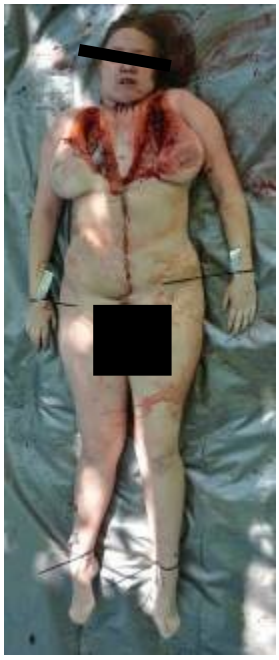

Figure C.39: D26-2015 (Tarp #5) at Placement

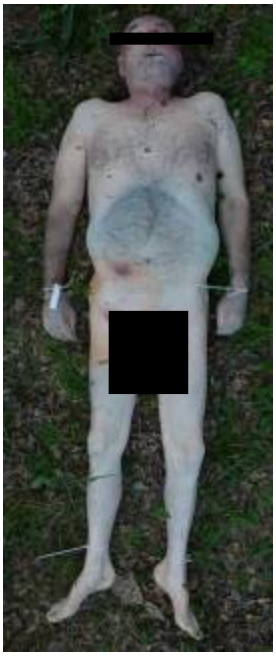

Figure C.40: D24-2014(Control #5) at Placement

Figure C.41: D26-2015 (Tarp #5) at 1000 ADD

Figure C.42: D24-2014(Control #5) at 1000 ADD

Figure C.43: D26-2015 (Tarp #5) at 1500 ADD

Figure C.44: D24-2014(Control #5) at 1500 ADD

Figure C.45: D26-2015 (Tarp #5) at 2000 ADD

Figure C.46: D24-2014(Control #5) at 2000 ADD

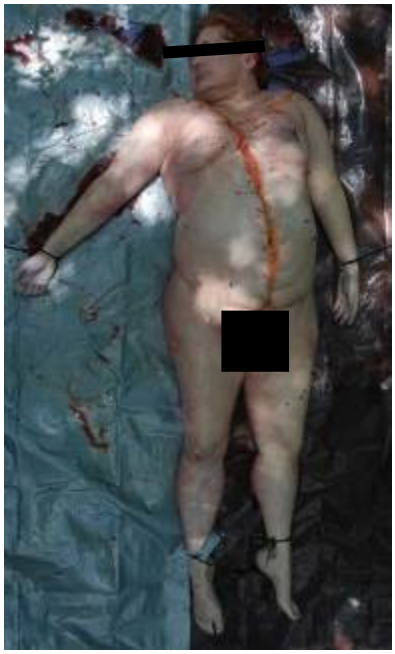

Figure C.47: D31-2015 (Tarp #6) at Placement

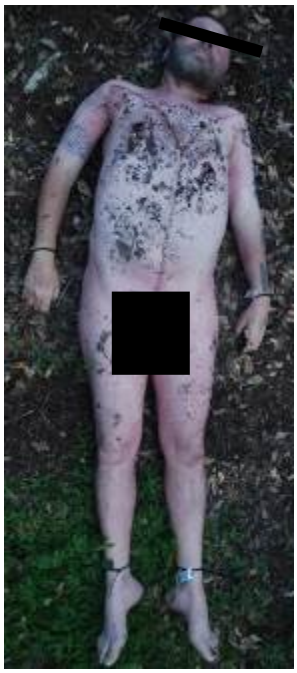

Figure C.48: D29-2015 (Control #6) at Placement

Figure C.49: D31-2015 (Tarp #6) at 500 ADD

Figure C.50: D29-2015 (Control #6) at 500 ADD

Figure C.51: D31-2015 (Tarp #6) at 1000 ADD

Figure C.52: D29-2015 (Control #6) at 1000 ADD

Figure C.53: D31-2015 (Tarp #6) at 1500 ADD

Figure C.54: D29-2015 (Control #6) at 1500 ADD

Figure C.55: D31-2015 (Tarp #6) at 2000 ADD

Figure C.56: D29-2015 (Control #6) at 2000 ADD

Figure C.57: D32-2015 (Tarp #7) at Placement

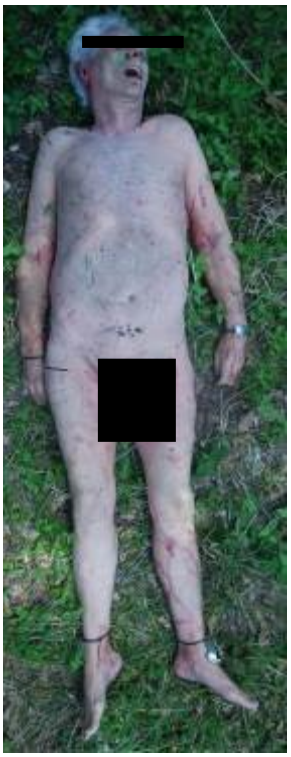

Figure C.58: D23-2015 (Control #7) at Placement

Figure C.59: D32-2015 (Tarp #7) at 500 ADD

Figure C.60: D23-2015 (Control #7) at 500 ADD

Figure C.61: D32-2015 (Tarp #7) at 1000 ADD

Figure C.62: D23-2015 (Control #7) at 1000 ADD

Figure C.63: D32-2015 (Tarp #7) at 1500 ADD

Figure C.64: D23-2015 (Control #7) at 1500 ADD

Figure C.65: D32-2015
(Tarp #7) at 2000 ADD

Figure C.66: D23-2015
(Control #7) at 2000 ADD

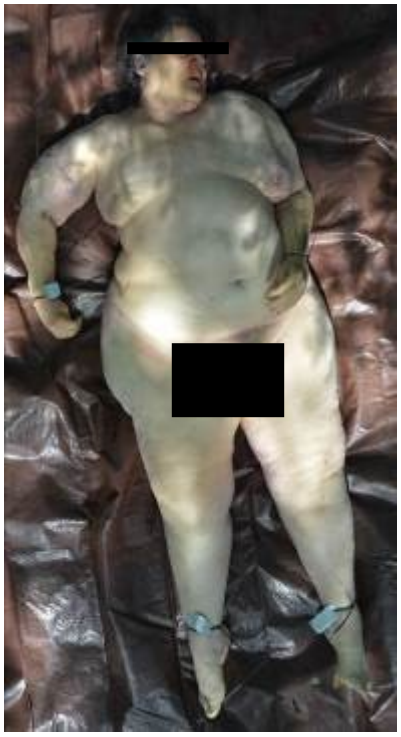

Figure C.67: D34-2015
(Tarp #8) at Placement

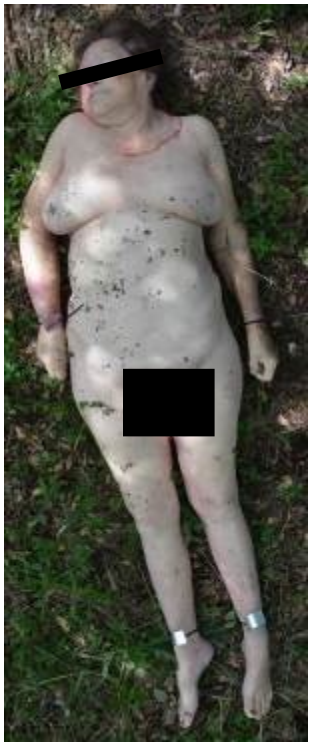

Figure C.68: D35-2015
(Control #8) at Placement

Figure C.69: D34-2015
(Tarp #8) at 500 ADD

Figure C.70: D35-2015
(Control #8) at 500 ADD

Figure C.71: D34-2015
(Tarp #8) at 1000 ADD

Figure C.72: D35-2015
(Control #8) at 1000 ADD

Figure C.73: D34-2015 (Tarp #8) at 1500 ADD

Figure C.74: D35-2015 (Control #8) at 1500 ADD

Figure C.75: D34-2015 (Tarp #8) at 2000 ADD

Figure C.76: D35-2015 (Control #8) at 2000 ADD

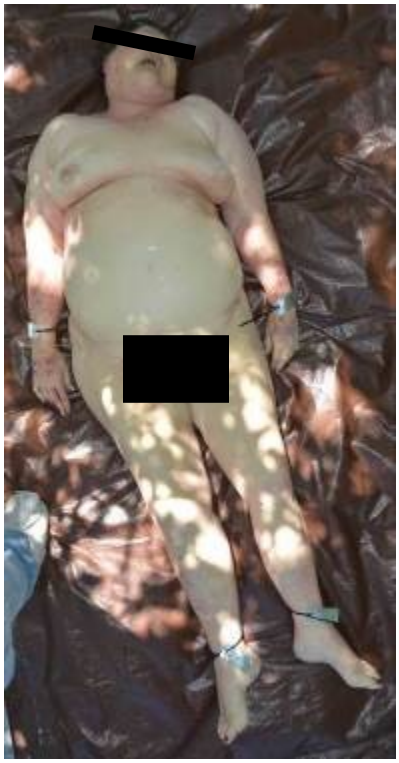

Figure C.77: D38-2015
(Tarp #9) at Placement

Figure C.78: D39-2015
(Control #9) at Placement

Figure C.79: D38-2015
(Tarp #9) at 500 ADD

Figure C.80: D39-2015
(Control #9) at 500 ADD

Figure C.81: D38-2015
(Tarp #9) at 1000 ADD

Figure C.82: D39-2015
(Control #9) at 1000 ADD

Figure C.83: D38-2015
(Tarp #9) at 1500 ADD

Figure C.84: D39-2015
(Control #9) at 1500 ADD

Figure C.85: D38-2015
(Tarp #9) at 2000 ADD

Figure C.86: D39-2015
(Control #9) at 2000 ADD

Figure C.87: D41-2015
(Tarp #10) at Placement

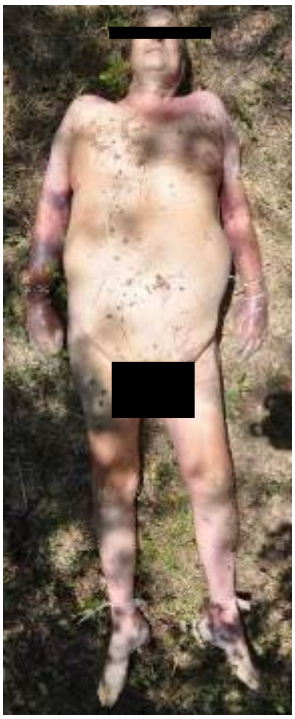

Figure C.88: D38-2014
(Control #10) at Placement

Figure C.89: D41-2015 (Tarp #10) at 500 ADD

Figure C.90: D38-2014 (Control #10) at 500 ADD

Figure C.91: D41-2015 (Tarp #10) at 1000 ADD

Figure C.92: D38-2014 (Control #10) at 1000 ADD

Figure C.93: D41-2015 (Tarp #10) at 1500 ADD

Figure C.94: D38-2014 (Control #10) at 1500 ADD

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