THE EFFECTS OF CLOTHING ON VULTURE SCAVENGING AND SPATIAL DISTRIBUTION OF HUMAN REMAINS IN CENTRAL TEXAS

by

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Though I know it is typically the norm to first thank your advisor, and other members of your committee in this section, I choose to be a little untraditional by staying true to myself and thanking the person that first comes to mind: My mom. I lost my mom two months almost to the day before I started this master's program, and I know that she is the main reason I am where I am. So, I have to first say thank you to Beverly Lewis, for believing in me and supporting me all throughout my academic ventures. I thank her for encouraging me to pursue my love of forensics, and being so very proud of me, even in her sickest moments. I didn't quit because of her, and for that, I am very thankful.

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ABSTRACT

Vultures and other animal scavengers have the ability to feed on human remains, which can lead to rapid tissue loss as well as movement of body parts over time. This can lead to misinterpretations of the scene and incomplete recovery of evidence. What is not known, however, is how clothing may affect how vultures feed on human remains and in turn how that may affect the spatial distribution of the remains. This thesis seeks to explore the effects of clothing on vulture scavenging and spatial distribution of human remains in Central Texas.

Five donated human subjects were dressed in a white t-shirt, blue jeans, socks, and tennis shoes prior to placement at the Forensic Anthropology Research Facility (FARF) at Texas State University. Upon placement, traditional baseline measurements were made to document the placement area and compare to final positions. A drone flew over to capture aerial photographs. During the data collection period for each individual, visual observations, notes, digital photography, and game cameras were used to monitor the subjects. Once the observation period was over for each individual, baseline measurements were taken again in order to document where the scavenged remains were dispersed. The study period refers to the observation time from placement until final data collection. All data for clothed individuals was compared to subjects from past vulture studies using unclothed human subjects. Statistical differences in average feeding times were analyzed using a Welch's t-test. All baseline measurements were plotted on scatter plots with different colored polygons drawn around each scatter (placement and final) for

each clothed individual. GPS data from the unclothed subjects were exported into Google Earth Pro, where polygons were also drawn around each scatter for each unclothed individual. Area was calculated for these polygons within Google Earth. In order to assess postmortem interval (PMI) estimations, weather data was collected and known accumulated degree days (ADD) was calculated for each individual. Total Body Score (TBS) was then assessed for each individual using the Megyesi et al. (2005) method. Estimated ADD was also calculated for each individual using this method. Inaccuracy and bias were then determined for each individual in order to compare known and estimated ADD. Spearman's rank test and t-test further provided information regarding the utility of this method.

Results of this study were presented in terms of feeding pattern/duration, spatial distribution, and ADD/PMI estimations. The differences in feeding pattern and duration between clothed and unclothed remains were determined to be statistically non-significant. Further, the differences in spatial distribution between clothed and unclothed remains were also determined to be non-significant. Though there were no statistically significant differences in these areas of the study, some useful information could be extracted from the results. Comparisons of known ADD to estimated ADD calculated via the Megyesi et al. (2005) method showed that this method consistently overestimated the PMI of the clothed, vulture-scavenged subjects. There was also a correlation between the inaccuracy of the estimated ADD and length of time vultures fed: the longer vultures fed on a subject, the more inaccurate the ADD/PMI estimate.

I. INTRODUCTION

Research Problem

Scavenging of human remains by birds and mammals can significantly alter the recovery of bones, interpretations of the taphonomic history, and ultimately the estimation of the postmortem interval (PMI) in medicolegal death investigations. Previous studies on animal scavenging have largely focused on mammalian scavengers, with minimal research focusing on avian scavengers, such as vultures. Longitudinal studies performed by Goff (1992) and Komar (1998) show that over half of forensic cases are clothed. This means that in these cases it is more than likely to find clothing associated with human remains. However, minimal studies have been conducted surrounding the effects of clothing on taphonomic agents (e.g. decomposition, scavenging, skeletal bleaching, etc.). Further, clothing has been found associated with individuals from the unidentified migrant recoveries within Texas and Arizona over the last several years, where vultures are known to scavenge (Ballejo et al. 2016). Though there have been a small number of published studies regarding vulture scavenging (Reeves 2009; Spradley et al. 2012; Dabbs & Martin 2013; Beck et al. 2015; Ballejo et al. 2016), no research currently exists that specifically investigates how clothing affects the pattern of vulture scavenging and the spatial distribution of human remains or the estimation of the postmortem interval (PMI). With the ongoing discovery of the clothed remains of Mexican and Central American border-crossers, studying decomposition in clothed remains in Central Texas is useful to the field of forensic anthropology here in this region. Additionally, vultures are known to be active scavengers in many geographical locations, especially Central Texas (Pharr 2015). Therefore, it is important that we understand if clothing affects the parts of the body that are scavenged by vultures, which elements are scattered, the distance the elements are scattered from the decomposition site, and how the rapid loss of soft tissue may alter interpretations of the taphonomic history and the approach forensic anthropologists take when estimating the PMI.

Purpose of Study

Animal scavenging has the potential to affect the discovery, recovery rate, estimations of PMI, and general taphonomic processes, making it more difficult to interpret the scene. The performed study compared clothed and unclothed individuals that were exposed to vulture modification. This is the first known study to examine the effects of clothing on vulture scavenging. The purpose of this thesis was threefold. First, the study assessed if clothing affects the pattern and/or feeding time of vulture feeding on human remains. Second, the study examined the effects of clothing on the spatial distribution of major elements. Third, the study examined the effects of vulture scavenging on the estimation of the PMI of clothed human remains. Understanding the effects of clothing on vulture scavenging may help forensic anthropologists better interpret a scene, make a more complete recovery of remains, discern between perimortem or antemortem injuries and postmortem damage, and better estimate the PMI in clothed individuals.

Background

The fate of human remains after a person dies is dependent upon numerous intrinsic and extrinsic factors (Manifold 2012). Taphonomy is the study of the environmental, chemical, physical, and cultural processes that occur after an individual's death (Lyman 1994, 2010; Nawrocki 1996). These processes lead to the postmortem changes that can make it more difficult for forensic anthropologists to recover remains and accurately determine the PMI – something they are often asked to do. Modification of human remains via animal scavenging is one example of such taphonomic process (Campobasso et al. 2001). Research has suggested that scavenging by particular animals can increase the rate of decomposition in human remains (Spradley et al. 2012). According to Spradley et al. (2012), rigorously investigating the sequence and markings of specific scavengers on human remains may prove to be useful in improving recovery and PMI estimations.

Vultures are carrion scavengers that have the ability to out-compete other scavengers in locating and feeding on carrion (Spradley et al. 2012; Pharr 2015). The two most common species of vultures are the American black vulture (*Coragyps atratus*) and the turkey vulture (*Cathartes aura*) (Reeves 2009). These birds have expanded geographically over the years, increasing the potential to be found within human environments (Reeves 2009). Turkey vultures have a large olfactory bulb, and they rely primarily on smell to locate remains (Bang 1946; Reeves 2009). Black vultures, on the other hand, have a reduced sense of smell, and generally rely on turkey vultures to help locate remains (Reeves 2009; Pharr 2015). Turkey vultures and black vultures are both obligate carrion feeders and will feed on dead animals of all sizes, including humans (Reeves 2009; Spradley et al. 2012). What is not known, however, is how clothing may affect the normal ability for vultures to locate and systematically feed on remains. This is important because, as mentioned before, forensic cases and cases of undocumented border-crossers are often clothed and, human remains exposed to the outdoor elements in

Texas and Arizona are at high risk for vulture and other animal scavenging that may confound interpretation of the scene (Beck at al. 2015; Reeves 2009; Spradley 2012).

Past vulture scavenging studies have examined the feeding pattern of vultures on human and animal remains, assessing the duration of feeding and the general order in which particular areas of the body are scavenged. For example, in the study conducted by Reeves (2009) using clothed pig carcasses, she found vultures began feeding on the remains about 24 hours after placement, on average, and were able to completely skeletonize the remains after feeding for 3-27 hours. She also found the mandible to consistently be the first element disarticulated from the body, and observed a vulture carry away a vertebra (Reeves 2009). Though her pig subjects were clothed, Reeves' (2009) study did not comment specifically on the effects of the clothing, nor did she compare her subjects to unclothed remains. A similar study using clothed pigs in two environments (sun and shade) was conducted by Beck et al. (2015) to assess the effects of animal scavenging on decomposition and taphonomy in border-crosser deaths in Arizona. Though this study looked at animal scavenging in general, vultures ended up being a main scavenger of interest in the study (Beck at al. 2015). In the sun-exposed pig, they observed turkey vultures within one day of placement; however, feeding did not occur until 17 days after death (Beck et al. 2015). Within 24 hours, the sun pig was completely skeletonized, and vultures were observed moving skeletal elements after skeletonization (Beck et al. 2015). Again, though the pig subjects were clothed, little was said about the effects of clothing on the scavenging. In another study conducted by Spradley et al. (2012) using unclothed human subjects, they found it took 37 days before vultures began to actively scavenge the remains, and they skeletonized the body within 5 hours. Dabbs &

Martin (2013) conducted a study assessing the taphonomic effects of vulture scavenging in Illinois, where there is a different environment and different vulture distribution than in Texas. In their study, they found only black vultures fed on the remains, exhibiting a delayed arrival time and skeletonizing the body between 8 and 39 days. In each of their trials, vultures began feeding by consuming anal tissue (Dabbs & Martin 2013). The study conducted by Ballejo et al. (2016) examined the taphonomy and spatial distribution patterns of New World vultures and crested caracaras in Northern Patagonia using sheep and rabbits as study subjects. In their study, they found the vultures and caracaras consumed the adult sheep in an average of 3 hours and 23 minutes. Further, they describe one case (a rabbit subject) where consumption began with the eyes.

In the literature, vultures have been shown to scatter remains, distributing different parts of the body to different locations of varying distance (Spradley et al. 2012; Beck et al. 2015). In addition to feeding pattern, Spradley et al. (2012) examined the effects of vulture scavenging on the spatial distribution of human remains. In their study using unclothed human subjects, they found that vultures scattered the remains a maximum distance of 11.7 meters from the original placement site by the end of their study. Beck et al. (2015) found that the vultures scattered the remains of the sun pig a maximum distance of 27 meters, with most elements found 1-5 meters away from the original placement. Ballejo et al. (2016) had much less dispersal distances than the previous studies. Studies like these may aid in the development of predictive models of vulture scavenging, which could potentially help more fully recover skeletal remains (Spradley et al. 2012).

The postmortem interval (PMI) refers to the time that has elapsed between death and discovery. To aid in estimations of PMI based on gross observations of the body, Megyesi et al. (2005) developed the Total Body Score (TBS) method and a regression formula for calculating accumulated degree days (ADD) based on the TBS score. ADD provides a means of standardizing the energy available for decomposition due to temperature, therefore allowing for comparison across different geographical regions (Myburgh et al. 2013; Edwards et al. 1987). In the Megyesi et al. (2005) method, the stage of decomposition is assessed separately for three regions of the body: head/neck, limbs, and torso. A score is assigned to each area based on the stage of decomposition. The lowest total score that can be assigned is a 3, and the highest total possible score is a 35. Calculated TBS is then placed into the regression formula to calculate ADD, which can be compared to local weather data to estimate the PMI.

Research Questions

This study investigated the effects of vulture scavenging on clothed human remains by comparing clothed and unclothed individuals that have been exposed to vulture modification in Central Texas. Specifically, I wanted to focus on three major questions that would increase our understanding of how scavenging of clothed human remains affects the recovery, interpretation of the taphonomic history, and the estimation of the PMI:

1) Does clothing affect the initial contact, pattern of feeding, and duration of feeding by vultures?
2) Does clothing affect which skeletal elements are scattered and how far they will be scattered away from the body?

3) How does vulture scavenging of clothed remains affect the estimation of PMI using the Megyesi et al. (2005) method?

II. MATERIALS AND METHODS

Sample

Because this study involved deliberate exposure of human remains to vultures, approval from the Institutional Animal Care and Use Committee (IACUC) was required. On April 27, 2016, I submitted an application for IACUC approval. Approval was granted on June 20, 2016. This approval was extended to last until June 30, 2017.

Human bodies used in this study came from donations to the Willed Body Donation Program of the Forensic Anthropology Center at Texas State. Research was conducted at Freeman Ranch, where the outdoor Forensic Anthropology Research Facility (FARF) is located. Subjects were identified using their given Donation ID numbers. To protect the vultures, individuals that knowingly underwent chemotherapy or other drug therapies that could harm the birds were excluded from the study. However, individuals were used regardless of age, sex, ancestry, or other causes of death. A weight limit of 250lbs. was enforced to ease the process of putting clothing on the individuals. Additionally, fully autopsied remains were not used, though one subject in the sample underwent a cranial autopsy. In this case, the organ bag was removed from the skull once access was gained (to further protect the vultures), and the calotte was excluded from the analyses to reduce bias of movement of this particular part of the body.

Clothed Sample

Sample size for the clothed individuals in this study was n=5. The clothed individuals were dressed in white cotton t-shirt, blue denim jeans, white socks, and black tennis shoes, which was representative of ‘common’ clothing found on deceased individuals from medicolegal investigations, including border-crossers (Beck et al. 2015).

All clothing remained constant between subjects (i.e. style and brand) throughout the study. During normal intake procedures upon arrival of a donation, each subject was also measured around the waist to determine approximate jean size and foot length (in cm) was used to determine approximate U.S. shoe size; a shoe-size chart was used to facilitate this. Once these sizes were determined, the individual was fully dressed and placed in the cooler for next day or future (no more than 3 days from arrival) placement. This was done to give the drone operator at least one-day notice before placement and flyover.

Control (Unclothed) Sample

Total sample size for the unclothed subjects used in this study was n=7. Existing data (photographs and GPS data) from unclothed individuals used in previous vulture scavenging research at the Freeman Ranch facility served as controls for the study. These previous studies were conducted by Dr. Kate Spradley, Dr. Michelle D. Hamilton, and Dr. Alberto Giordano from Texas State University; the data used for this thesis was a mixture of published (Spradley et al. 2012) and unpublished data. Permission was received by all researchers to utilize the unpublished data in this study. Three individuals were used for the feeding pattern/duration portion of the study (D45-2013, D22-, D50-2015), while a total of five individuals were used for the spatial distribution portion. Definitions and more in-depth explanation of how feeding pattern/duration was determined is below. The control sample was broken up due to what was available to me for fair comparisons in feeding pattern/duration versus spatial distribution. To be more specific, extensive game camera photographs were not available for all the unclothed individuals utilized for the control sample in the spatial distribution portion. This meant that feeding duration/pattern in all five cases used for spatial distribution could not be calculated and/or assessed in the same detail as the clothed remains in this study (i.e. four out of five individuals with GPS data did not have sufficient game camera photos for comparison to this study). To account for this as best as possible, game camera photos from two other individuals that were unclothed and vulture-scavenged were used instead. Though one of these additional individuals (D22-2014) came from game cameras used in Spradley, Hamilton, and Giordano's unpublished vulture study, game camera photos from the third individual (D50-2015) came from a past thesis conducted by Pyle 2016.

Placement and Monitoring of Sample

FARF is enclosed by a fence to keep terrestrial scavengers out; however, the clothed subjects were placed in a relatively tree-free area of the research facility with no cage covering the body, exposing it to avian scavengers. To reduce the chance of commingling of remains, individuals were placed at least 25 meters apart from each other. In order to examine the spatial distribution of the remains at the end of the study, a datum and 30-meter baseline for each individual was established and marked immediately after placement by inserting stakes into the ground. Five motion-sensing game cameras, one for each individual, were set up to monitor the activity associated with each subject throughout the study. These game cameras were mounted on wooden posts inserted into concrete-filled buckets to allow the cameras to be weighted and still mobile in the case scavenging pulled the remains out of the original frame. Game cameras work in general by detecting and responding to motion and heat (infrared for night vision). In addition to movement response, game cameras can be programmed to photograph in desired time intervals. Using an infrared camera allows subjects to be photographed at night with minimal mechanical noise and without a visible flash.

Data Collection & Analyses

The data collection for each subject in this study occurred for a period of at least four weeks, beginning after initial placement of the subject. When vulture activity was delayed, observation was extended up to 12 weeks for sufficient data collection. "Study period" in this thesis refers to the time from placement until final data collection for a specific individual. Data collection in general was ended when vulture activity greatly slowed and/or ended for approximately two weeks consecutively. Methods were conducted according to research questions, which are explained below.

Question 1: Feeding pattern/duration

Observations regarding feeding pattern of the clothed remains were primarily made using game camera footage and visual observations with the date and time of placement, initial vulture contact, initial scavenging, and skeletonization recorded. Feeding pattern in this study was defined as the sequence in which vultures fed on remains, the order of disarticulation and/or dispersal of elements, time until skeletonization (when applicable), and how the clothed remains were accessed. Prior to placement, each game camera was set up to display date, time, and camera identifier to be displayed on the photographs. Game cameras were mounted on wooden posts inserted into concrete-filled buckets for stability and mobility. The game camera was then positioned to capture the body and immediate surrounding areas. Upon placement, each game camera was checked daily to ensure they were functioning properly and pointed in the correct direction to capture the remains and surrounding area. Each day, the SD card was removed from the game cameras and inserted into a laptop for transfer. Once transferred, the SD card was replaced, and the game camera was checked for functionality. During data collection, some data related to feeding duration was lost for one subject (D54-2016) due to malfunctioning of one of the game cameras and uncorrected movement by vultures of the same game camera during time away, when game cameras were checked by others. Because of this, the individual (D54-2016) was removed from this part of the analysis.

In-person observations for each clothed subject were made by regularly taking a series of digital photographs, and recording any observations about decomposition, such as insect activity, stage of bloat, odor, skeletonized elements, etc. To be thorough and keep in line with protocol for the longitudinal study ongoing at FARF, digital camera photos included: The Donation ID stake, anterior face, sides of the face, arms, legs, sides of torso and an overall. The notes on the observations were documented using the Taphonomic Form also used in the longitudinal study.

Patterns of vulture scavenging on the clothed remains were recorded daily after first contact using digital and game camera footage and/or visual observations. Essentially, this was monitoring the sequence in which vultures scavenged different areas of the body, and how long it took to achieve skeletonization. The camera data was also used to determine total feeding time of the vultures on the human remains. This was assessed by examining the time between initial scavenging and skeletonization (or end of study period for that subject). To achieve the best accuracy, each game camera photo was assessed for feeding. For simplification, in this study feeding referred to any time that at least one vulture was seen on the game camera physically at and/or around the body interacting with remains. For each subject all time ranges of vulture feeding were recorded by hand and then added together to yield a total feeding time. Published and unpublished data collected by Spradley, Hamilton, and Giordano was used as control data for comparison. Game camera photos were assessed to determine total feeding time and number of days vultures fed on unclothed remains. Differences in sample sizes between clothed and unclothed remains in this portion of the study are due to the availability of game camera photos from the past studies. In other words, game camera photos could not be located for all five unclothed individuals used in the spatial distribution portion of the study. Statistical differences in average feeding times between clothed and unclothed remains were analyzed using a Welch's t-test. This type of t-test is used in situations when two samples have unequal variances and unequal sample sizes. This same t-test was used to analyze differences in the number of days vultures spent feeding on clothed versus unclothed remains. The feeding pattern of the vultures on the remains was analyzed through observational data via game cameras and taphonomic notes.

Question 2: Scattering of remains

Upon placement, an unmanned aerial vehicle (UAV) operator conducted flyovers at various heights (7.5, 17, and 33 meters) and captured the original placement positions of each subject via aerial photography. Prior to this, black and white painted aerial targets measuring 2' X 2' were placed on four corners within the placement area. To enable assessment of the distribution of remains, two methods were used. To document location of where the remains were placed, traditional baseline measuring was completed prior to drone flyover. A baseline was established alongside each subject as a means to determine which elements have been moved, and how far from the placement site; the 30-meter baseline was established by driving stakes into the ground. The baseline was of this length to adequately cover the possible area of scatter for final measurements. At the time of placement, the location (X and Y axes) of the head and major joints and other areas (shoulders, elbows, wrists, distal hands, hips, knees, ankles, and distal feet) were recorded. At the end of the observation periods (when vulture activity appeared to have ceased), these same measurements were taken again. Final drone flyovers were conducted on the same day, to capture aerial photographs of the scene at the end of the observation period.

The scattering data via notes and digital photographs was checked against game camera footage to ensure the movement was in fact due to vultures, and to see if other scavengers were involved. Other than crested caracaras, a red-tailed hawk, and insects, no other species were observed scavenging the remains. Control data adopted from the previous published and unpublished studies conducted by Spradley, Hamilton, and Giordano were collected using Trimble's *GeoExplorer XT*® hardware, associated postprocessing software, and ESRI ArcGIS (Spradley et al 2012). A Trimble *GeoExplorer XT*® is a form of handheld GPS device used to take on-site GPS points with relatively high accuracy. Because the control data was primarily in GPS/GIS format, a few modifications had to be made to the data to make it comparable to the experimental data. The corrected Trimble files (.cor extension) were exported into Google Earth Pro format (.kmz extension). For each unclothed individual (unpublished data from Spradley et al.), the files associated with placement and final data collection were opened simultaneously in the same Google Earth Pro window so that both datasets would appear together on one map. The map was then zoomed in until the points and associated labels were clearly discernible. For each dataset, a polygon was drawn around the points using the Ruler tool. Again, a polygon shape was chosen to better enclose all the points to determine the placement and final areas; this was based on the idea of the convex hull, which is the tightest boundary around a set of data point. A Visual Basic Application (VBA) created for calculating the convex hull in Microsoft Excel was tested for the clothed remains but did not create a very tight boundary around the points. Instructions on using the VBA claimed the ability to change settings that would further restrict or expand the Convex Hull, but no information or menu item on the VBA interface indicated how to perform this action. Instead, polygons were drawn in to more accurately calculate and compare the areas of spatial distribution in this study. The areas of the polygons were automatically calculated in Google Earth once the drawings were completed. Altogether, five Google Earth maps with polygons were created for comparison to the polygons of the clothed remains. Average differences in areas for clothed and unclothed subjects were calculated using the polygon data by subtracting the placement areas from the final areas, adding the differences, and dividing by five (sample size).

Scatter plots of the five clothed individuals in this study were created using Microsoft Excel. Each plot represents a different subject and contains the placement measurements and the final measurements. Before any area calculations could be determined, each scatter plot had to be scaled by hand. A polygon was then drawn over each set of data points. The coordinates of the vertices of the polygons were then determined in order to calculate the areas of the polygons. Area of a polygon is calculated using the formula:

$$| (X_1Y_2 - Y_1X_2) + (X_2Y_3 - Y_2X_3)\ldots+ (X_nY_1 - Y_nX_1)/2|.$$

Though the scatter data is plotted in centimeters, all areas are reported in square meters. Average difference in area was calculated using the polygon data. The average values from this study were compared to the average values of unclothed vulture-scavenged remains by conducting a Welch's t-test.

The drone photography was utilized to show before and after aerial shots as an additional means of visualizing the spatial distribution of the clothed remains.

Question 3: Estimations of PMI

Data related to estimating the PMI was collected by calculating ADD and determining TBS. Local temperature data was gathered from Weather Underground for San Marcos, TX in order to calculate ADD from day of placement, to the day of vulture arrival, to the end of the study period. The accuracy of the weather data in Weather Underground was tested by comparing temperatures between Weather Underground and the HOBO weather station data from FARF for a series of days. There was no statistically significant difference in temperatures. A baseline temperature of 0°C (32°F) was used to calculate ADD. A "baseline temperature" is referred to as the temperature point in which certain processes (like decomposition) end. Though it is unknown the exact point in which the decomposition process ceases, it is generally known that freezing temperatures greatly decrease and/or halt decomposition. Known ADD was calculated by taking a daily average of the high and low temperatures from day of placement to day of final drone flyover. On the days when it was freezing or below freezing, the temperature was recorded as "0" to avoid any negative values (Megyesi et al. 2005). Degree days were summed together daily in order to get the accumulated values.

TBS scores were determined at the end of the study period for each individual; the legs were scored by removing the jeans if still on the body. Due to movement and fabric deterioration, the t-shirts did not interfere with scoring the arms or the torso. For efficiency, digital photographs were taken after final drone flyovers and pants removal, and TBS of the head, torso, and limbs was subsequently assessed through photographs. The TBS scores were entered into the Megyesi et al. (2005) equation to yield estimated ADD values. This estimated ADD data for each individual was then compared to known ADD and used to look for bias and inaccuracy. Bias provided information about whether the Megyesi et al. (2005) equation systematically under- or over- estimated the ADD for each individual. The examination of inaccuracy provided information about how accurately the Megyesi et al. (2005) equation estimates the actual ADD that has elapsed for clothed and vulture-scavenged individuals. A Spearman's rank correlation test was used to evaluate the strength and direction of the relationship between estimated and known ADD.

III. RESULTS

Feeding Pattern/Duration

On average, it took about 8.6 days for vultures to begin feeding on the clothed remains. In unclothed remains it took an average of 11 days for vultures to begin feeding. A t-test determined these differences were not statistically significant ($p = 0.79$, $\alpha = 0.05$). In the clothed individuals, the vultures were able to access the upper parts of the body with no issues, despite the t-shirts. Though the jeans appeared to limit access to areas of the remains initially, vultures can be seen on game camera images accessing the innominates and the ankles/ lower tibiae and fibulae by reaching their heads into the waist and up the legs of the jeans (Figure 1). Either prior to this, or sometime during this effort, the vultures were able to remove the socks and shoes from three of the five clothed subjects (Figure 2). In two cases, vultures were able to completely remove the jeans from the body, which allowed them to access the entire body in a similar manner as with unclothed individuals. However, in the cases where the jeans remained on the body the entire study, the legs still contained a significant amount of tissue when compared to other areas of the body. No other discernible scavenging patterns were observed in terms of clustering of particular areas of the body in the clothed remains when compared to unclothed remains. For each clothed subject, though, observations were made that were consistent with vulture scavenging patterns discussed in the literature (Reeves 2009; Spradley et al. 2012). For example, the vertebral column in all five clothed subjects remained almost completely intact. Also, apart from mummified skin remaining on a couple of the subjects, all visible (i.e. not covered by clothing) remains were completely skeletonized, leaving only some cartilage behind on the joint surfaces.

Figure 1. Game Camera Photo of Vultures Accessing Body. Game camera photo showing an example of vultures accessing the body through the waist and ankles of the jeans.

Figure 2. Game Camera Photo Example. Photo showing an example of a subject's shoes and sock removed as a result of vulture scavenging.

The average feeding time (total observed hours of feeding) of vultures was 31 hours and 36 minutes (or 31.6 hours) and 17 hours and 1 minute (or 17.01 hours) for the clothed and unclothed cadavers, respectively. Table 1 shows the vulture feeding data for clothed and unclothed remains. Figure 3 is a boxplot that illustrates the distribution of the total observed hours feeding for clothed and unclothed individuals The Welch's t-test performed to determine significance of the differences in these feeding times showed the differences were not statistically significant ($p = 0.23$, $\alpha = 0.05$), although the variation and average feeding time for the clothed individuals was greater compared to the unclothed individuals. A Welch's t-test also determined the differences in total observed days feeding between clothed and unclothed remains was not statistically significant ($p = 0.13$, $\alpha = 0.05$). For reference, vulture counts are presented in Table 2.

Table 1. Vulture Feeding Times: Clothed & Unclothed Subjects.

Subject	Placement Date	Start of Vulture Feeding	End of Vulture Feeding	Total Obs. Days Feeding	Total Obs. Hours Feeding
Clothed					
D43-2016	9/24/2016	9/30/2016	11/3/2016	15	26 hrs,18 min
D53-2016	11/6/2016	11/20/2016	1/12/2017	24	9 hrs,27 min
D54-2016	11/19/2016	12/1/2017	1/19/2017	N/A	N/A
D06-2017	1/28/2017	2/5/2017	3/20/2017	33	35 hrs,45 min
D14-2017	3/21/2017	3/24/2017	4/23/2017	29	54 hrs,56 min
Unclothed					
D49-2013	9/24/2013	9/27/2013	11/25/2013	7	12 hrs
D22-2014	5/2/2014	5/27/2014	7/6/2014	23	25 hrs, 58 min
D50-2015	9/18/2015	9/23/2015	10/31/2015	12	13 hrs, 6 min

Figure 3. Distribution of Feeding Hours. Box plot showing the distribution of feeding hours in clothed versus unclothed remains.

Table 2. Vulture Counts for Clothed Remains.

Subject	Season(s)	# vultures 0-24 hours	# vultures 2-10 days	# vultures 11-20 days	# vultures 21-30 days	# vultures 30+ days
D43-2016	Fall	0	0-20	0-17	0-3	0-3
D53-2016	Fall/Winter	0	0	0-10	0-12	0-12
D54-2016	Fall/Winter	N/A*	N/A	N/A	N/A	N/A
D06-2017	Winter	0	0-11	0-16	0-15	0-6
D14-2017	Spring	0	0-20	0-12	0-11	0-4
Average Range		0	0-13	0-14	0-10	0-7

*N/A is for subject with game camera data loss.

Spatial Distribution of Remains

Game camera photos reveal extensive evidence of vultures physically moving elements around throughout the study (Figure 4). The calculated polygon areas for the clothed and unclothed subjects are presented in Tables 3 and 4. Figure 5 is an example of a scatter plot created for one of the clothed subjects (D43-2016). The legend in Table 5 corresponds to this figure. Figure 6 is an example of one of the Google Map plots for one of the unclothed subjects (D45-2013). The complete set of scatter plots and maps with the polygons that the areas were calculated from are presented in Appendix A. The farthest distance that an element was displaced from its original deposition site was for clothed subjects was 3.31 meters. The average difference in area from placement to final observation for the clothed remains was 3.346 square meters. The average difference in area from placement to final observation for the unclothed remains was 6.482 square meters.

Within the unclothed subjects, D10-2009 produced the largest difference in area from placement until final data collection (28.44 square meters), making it a potential outlier when comparing area values. The original study by Spradley et al. (2012) was conducted for approximately seven months (November-June). Because the clothed individuals in this study were placed for approximately two months, the cutoff point for the control data was also approximately two months. To avoid statistical errors when analyzing the data, the potential outlier was included and then later removed to check the effects. With this potential outlier removed, the average difference in area for unclothed remains was 0.89 square meters. T-test results comparing average differences in areas before and after placement (including the potential outlier) showed that the differences in areas between the two samples are not statistically significant ($p = 0.59$, $\alpha = 0.05$). Removing the potential outlier did not change the significance of the results. The results reported in the tables below include the potential outlier.

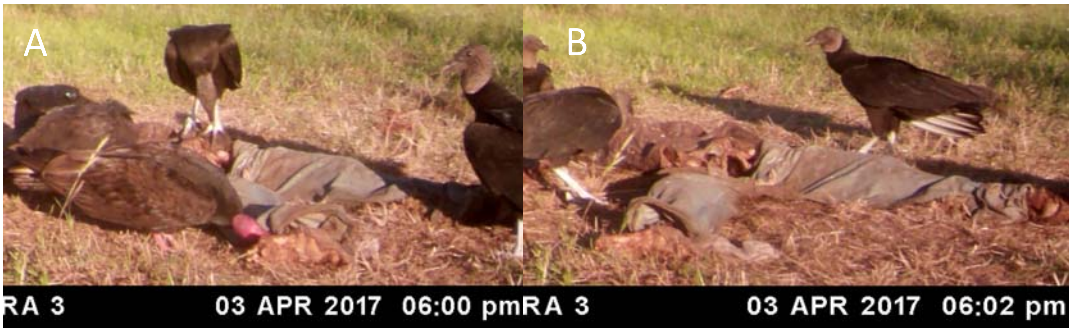

Figure 4. Example of Movement of the Right Foot/leg of One Clothed Subject. This figure illustrates an example of movement of the right foot/leg of one clothed subjects. The photo on the left is one position of the leg/foot (A). The photo on the right is the position of the leg/foot two minutes later (B), showing an overall widening of the legs.

Aerial photographs showing placement and final positions of the five clothed individuals are presented in Appendix B. (Note: not all elements are visible in the photographs due to size of elements as well as distance of dispersal).

Table 3. Changes in Polygon Area Size for Clothed Remains. This table shows the numerical values of the placement, final, and difference areas for each clothed subject.

Clothed			
Subject	**Placement Area** (m^2)	**Final Area** (m^2)	**Difference** (m^2)
D43-2016	1.32	3.51	2.19
D53-2016	1.39	2.32	0.93
D54-2016	1.64	9.42	7.78
D06-2017	1.59	4.87	3.28
D14-2017	1.56	4.11	2.55
Average Difference			**3.346**

Table 4. Changes in Polygon Area Size for Unclothed Remains. This table shows the numerical values of the placement, final, and difference areas for each unclothed subject.

Unclothed (Control)			
Subject	**Placement Area** (m^2)	**Final Area** (m^2)	**Difference** (m^2)
D45-2013	1.21	1.31	0.1
D49-2013	1.37	3.74	2.37
D62-2013	1.12	2.06	0.94
D64-2013	1.32	1.47	0.15
D10-2009	1.46	29.9	28.44
Average Difference			**6.400**

Table 5. Legend for Clothed Scatter Plots. This table is a legend showing the data label number and the corresponding major body part/area. This legend is related to the chart shown in Figure 5.

Data Label	Description
1	Top of Head
2	Chin
3	R Shoulder
4	L Shoulder
5	R Elbow
6	L Elbow
7	R Wrist
8	L Wrist
9	R Hip
10	L Hip
11	R Knee
12	L Knee

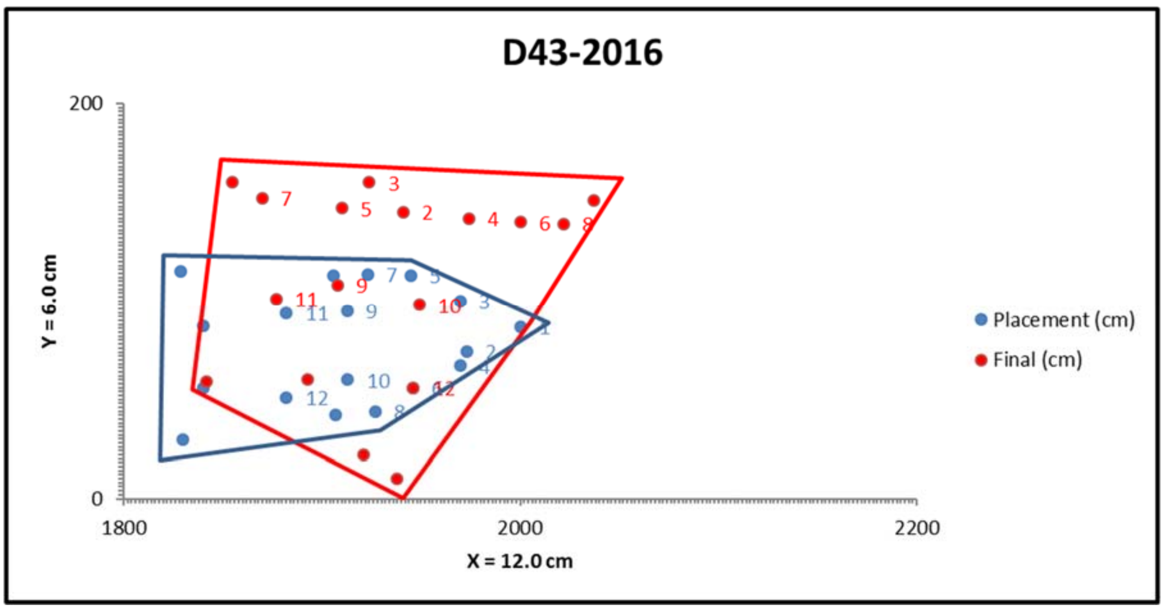

Figure 5. Spatial Distribution Example for Clothed Remains. This figure shows a spatial distribution plot for one of the clothed subjects. Blue dots represent anatomical landmarks taken at the time of placement. Red dots represent the distribution of the body at the end of the study period. Polygons are drawn around each set of points. Each data label is placed approximately 3 cm to the right of the data point. Axis dimensions are in the axis labels. Note: Final data point 1 (top of head in red) is removed due to cranial autopsy. See Appendix A for all subjects.

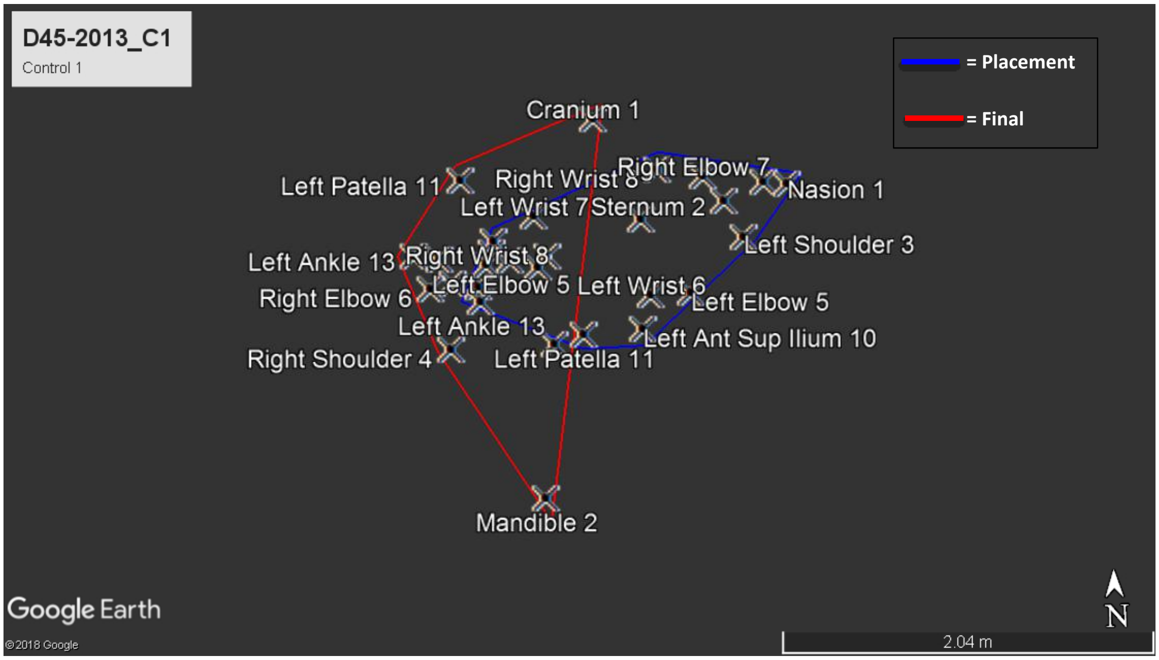

Figure 6. Spatial Distribution Example for Unclothed Remains. This figure shows a spatial distribution plot generated in Google Earth Pro for one of the unclothed subjects. See Appendix A for all subjects.

<u>ADD & Estimations of PMI</u>

The known ADD and estimated ADD for each clothed individual are represented in Table 6. A Spearman's rank correlation test yielded a correlation coefficient of 0.50. A two-tailed t-test showed a significant difference between known ADD and estimated ADD (p=.036). The mean inaccuracy is 1,318.8 with estimated ADD always greater than known ADD (negative bias). In two of the cases the estimated ADD value is outside the 95% confidence interval and three are outside the 68% confidence interval. All weather/ADD data as well as the TBS scores for each individual are reported in Appendix C.

Table 6. ADD Data Summary for Clothed Subjects. ADD point estimate, known ADD, bias, and inaccuracy for clothed individuals.

Subject	Known ADD	Estimated ADD[1]	Inaccuracy	Bias
D43-2016	1235	2388	1152.8	-1152.8
D53-2016	1188	1452	264	-264
D54-2016	945	2720	1775	-1775
D06-2017	912	1639	727	-727
D14-2017	833	3552	2719	-2719

[1]Based on TBS in Megyesi et al. (2005) equation. The standard error provided is 388.16 ADD.

IV. DISCUSSION

Feeding Pattern & Duration

The amount of time that it takes vultures to detect human remains in clothed and unclothed individuals was virtually the same. This was expected because vultures have such a strong sense of smell due to their large olfactory bulbs, and simply wearing clothing should not necessarily affect the ability to detect and locate a dead carcass. The stages of bloat and purge likely contribute to the vultures' location of remains, as no vulture scavenging activity in the clothed subjects was observed until some form of bloat and/or purge had occurred. Once the clothed remains were located by vultures, the initial feeding pattern was in some ways similar to that seen in past studies with unclothed remains (i.e. first going for the orifices and abdomen). With clothing on the bodies as well as placement being in a supine position, consumption of anal tissue specifically was not documented as in the previous study by Dabbs & Martin (2013). Also, the mandible was not consistently the first element disarticulated from the body as seen in the study conducted by Reeves (2009). In fact, the mandible remained articulated to the body in three out of the five cases. This difference may be due to the use of pig subjects versus human subjects, the differences in skeletal morphology between animals and humans (e.g. pigs have larger mandibles with larger joint spaces that may make it easier to disarticulate), as well as differences in how vultures may feed on animals versus humans.

After feeding on the orifices, vultures initially struggled to access the tissue on the lower extremities of the clothed remains due to the presence of blue jeans. This may have led to development of an "access strategy," where some vultures inserted their heads into the waist of the jeans and up the legs of the jeans as mentioned previously. In two cases, this strategy seemed to lead to the partial or complete removal of the jeans, which likely allowed for greater access to the entire body, increasing the amount of overall skeletonization, and therefore the estimation of PMI. In the other three cases where jeans were not removed, this strategy seemed to have allowed increased access to the innominates, the proximal femora, the distal tibiae, and the distal fibulae; mummified tissue remained on the midsections of the lower limbs in these cases. Additionally, the vultures were able to remove the tennis shoes as well as the socks and gain complete access to the feet.

Other than crested caracaras and a red-tailed hawk, no other scavengers (terrestrial or avian) were captured on game cameras feeding on the remains. However, it is possible that small or stealthy scavengers failed to trigger the motion sensors for capture on camera. It is also possible that an intermittent game camera malfunction occurred in between checks, preventing other scavengers from being captured on camera footage.

Though there were no statistical differences in feeding time and pattern between clothed and unclothed remains, there are still some observable differences to consider. For example, the feeding time distribution in clothed remains is a wider range than the unclothed distribution, meaning that vultures tended to feed a much more variable amount of time on clothed individuals when compared to unclothed individuals. This could be due to disturbances from increased human activity at the outdoor facility from 2009 to 2017. In this study, when vultures were disturbed, they flew away until it was clear to return to the body. Further, vultures appear to have accessed the clothed remains on more days than they accessed the unclothed remains. This may be partially due to the reduced ability to access the clothed remains, especially in the cases where the jeans remained on the body throughout the observation period. It should be noted, however, that there was no observable correlation between removal of the jeans and the overall time spent feeding on the remains.

One huge drawback in this portion of the study is that the sample sizes for feeding times in clothed and unclothed remains are not the same (n=5 vs. n=3, respectively). Not only that, but the sample sizes in each case are relatively small, which likely influences the statistical significance in these results. This highlights the importance of conducting further studies like these using larger sample sizes to confirm that clothing is not a confounding factor when dealing with forensic cases. Another drawback from the study was the reliance on the operability of the game cameras. Admittedly, and as mentioned previously, some game camera data was lost in this study due to malfunctioning of the camera (i.e. suddenly not responding to movement). In the future, if such a study is to be conducted, it is important to be proactive on how to deal with failing cameras. The use of multiple cameras for each body may improve documentation. In this study specifically, some data was lost due to movement of the camera seemingly by the vultures, combined with the inability to realize and adjust accordingly in a timely manner.

<u>Spatial Distribution</u>

The spatial distribution in the clothed remains did not statistically differ significantly from spatial distribution in unclothed remains. However, as with the feeding pattern/duration, there are some observations regarding spatial distribution that are worth noting. For example, there is no direct correlation between total vulture feeding time and dispersal distance of the clothed remains. This needs to be researched further, as there are conflicting conclusions regarding this relationship. Spradley et al. (2012) found that the longer the remains were placed (longer known PMI), the greater the spatial distribution (Suckling et al. 2015). However, the study conducted by Manhein et al. (2006) concluded that there was no specific correlation between PMI and distance or direction of dispersal of remains. Related to this, there appears to be no direct correlation between dispersal distance of clothed remains and the estimated ADD derived from the Megyesi et al. (2005) method. Also, the differences observed in the average areas between clothed and unclothed remains could be different based on the measurements of the one potential outlier in the control subjects. Though removing the potential outlier did not change the significance of the results, it did change the average value for the unclothed remains. With the potential outlier included, unclothed remains appear to spread a farther distance on average than clothed remains. This is what was initially expected, with the assumption that the clothing would impede accessibility to the remains, which would in turn affect the ability for vultures to move body parts any considerable distance from the original deposition site. However, with the potential outlier excluded, the clothed remains appear to spread a farther distance on average than the unclothed remains. In this case, having a higher average for difference in area in the clothed remains could be due to an increased effort in trying to access areas of the body that were covered with clothing. The eagerness of trying to access the covered remains could lead to a more aggressive approach in feeding, thus leading to more tugging and pulling that displaces body parts. Another observable difference between clothed and unclothed vulture-scavenged human remains in terms of spatial distribution was which elements were distributed the farthest. In this thesis study the element that spread the farthest from the original deposition site was the skull of subject D06-2017 (3.31 meters). In the published case by Spradley et al. (2012), the forearm dispersed the farthest from original deposition site (11.7 meters). The additional unpublished data used as the control data for this study did not necessarily follow this same pattern. This result may be related to the location of placement (if trees and high grass were in the area at time of placement), seasonality, and/or increased traffic in and out of the outdoor facility over time that may have affected vulture activity. The smaller dispersal distances seen in the study by Ballejo et al. (2016) involving sheep subjects may also suggest differences between the way vultures feed and disperse animals compared to how they feed and disperse humans.

Establishing observable patterns of spatial distribution in vulture-scavenged remains provides information on how far from the discovery site to search for additional remains and make a more complete recovery. Further, including clothed remains in scavenging and decomposition studies can further inform law enforcement and forensic specialists in multiple fields about how clothing plays a part in determining rates of decomposition and time since death. A similar study with a larger sample size is needed before any major generalizations can be made regarding the differences in spatial distribution between clothed and unclothed remains. It may also help in further studies to utilize that same method to gather spatial distribution data between the two different groups. More specifically, it likely makes more sense to exclusively collect GPS data for clothed and unclothed remains instead of baseline measurements to allow more consistent data collection and easier, possibly more accurate, comparisons.

ADD & Estimations of PMI

Past studies that have tested the Megyesi (2005) method around the country have shown the method to be inaccurate when used in certain geographical areas. For example, it has been shown that this method is not very reliable when used in a Central Texas environment (Suckling et al. 2015). The purpose of including this method in this thesis study was to show how vulture scavenging- or any animal scavenging that increases soft tissue loss- can have an effect on the accuracy of PMI estimations in Central Texas. In a method where it is already potentially flawed due to geographic variation, it is especially important to be careful when applying this same method in cases where vulture scavenging (or any other animal scavenging) has possibly taken place. Vulture scavenging, whether in clothed or unclothed human remains, has the ability to lead to rapid tissue loss, greatly affecting the TBS score assigned to such an individual. This means that when the TBS score of a scavenged individual is incorporated into the Megyesi et al. (2005) equation, it is already much higher than would be expected in an individual that has not been exposed to scavenging. In this study, the Megyesi et al. (2005) method consistently overestimated the ADD/PMI, making it appear as though all clothed subjects had died later than they actually had. This information is important when considering missing persons reports, timelines, alibis, etc., as a means of narrowing down the population for making positive identifications.

It is also important to note that the total amount of time vultures fed on the clothed remains was directly proportional to the inaccuracy and bias of the PMI. Vultures fed for the least amount of time on subject D53-2016, which had the lowest inaccuracy and bias (i.e. produced the most accurate estimation). Vultures fed for the longest amount of time on subject D14-2017, which had the highest inaccuracy and bias (i.e. produced the least accurate estimation). In other words, the longer that vultures spend actually feeding on human remains, the more inaccurate the PMI estimation will be when applying the Megyesi et al. (2005) method. This is likely true whether the individual is clothed or unclothed. Though it is impossible to determine how long vultures will feed on each set of human remains it consumes, studies such as these highlight the importance of considering the development and application of some type of formula correction or for obviously scavenged remains in different geographical areas. The ultimate goal would be to develop a correction or multivariate approach that applies to each individual animal scavenger within these areas, however, conducting studies that begin with one particular scavenger- such as vultures- is where this effort needs to begin. If evidence of vulture scavenging in clothed and unclothed remains can be recognized, the PMI estimations can likely be reduced or modified from the estimation the Megyesi et al. (2005) method would provide. Future studies should place an adequate sample of clothed and unclothed individuals to compare the accuracy of PMI estimations in clothed versus unclothed vulture-scavenged remains to confirm there are no significant differences. In terms of real-world application, it is critical that law enforcement and forensic personnel learn how to recognize the signs of vulture scavenging in clothed and unclothed remains so as not to automatically assume that an individual went through all of the stages of decomposition, which will affect the accuracy of PMI estimations.

V. CONCLUSION

This thesis has explored the differences between clothed and unclothed humans who are exposed primarily to vulture scavenging. One valuable application for this study and studies like these is within the realm of humanitarian crises, such as the one at the U.S.-Mexico border. As a contributor to the efforts of Operation Identification, I know firsthand that many individuals found deceased along the border have personal effects associated with them, including but not limited to clothing. And although many of the individuals recovered have been excavated from graves, it is clear that some of these individuals have been exposed to the elements prior to discovery. Unfortunately, this has led to incomplete recovery of skeletal elements in some of these cases. If law enforcement is more knowledgeable about vulture scavenging and spatial distribution of clothed remains, they may be able to more accurately determine and secure a search area that may lead to a fuller initial recovery of discovered remains. This can in turn lead to more evidence that can better inform a positive identification as well as lead to returning a more complete skeleton to the families of the deceased.

This study can also inform situations where clothing is missing from the body. For example, forensic anthropologist Lauren Pharr, PhD of Pharr Forensic Consulting LLC recently had a forensic case where a person was found deceased wearing no clothing (conversation with Pharr 2018). Law enforcement was curious if vultures could have carried off the clothing. Based on evidence from this study, vultures have the ability to move clothing small distances, but it is highly unlikely that vultures would carry clothing completely out of the vicinity of the body. This is important when trying to make a distinction between clothes being removed by scavengers or a person being dumped at a scene wearing no clothing.

This study has broader implications that go well beyond helping forensic anthropologists recover skeletal remains. When dealing with missing persons or medicolegal death investigations, no matter the circumstances, this can affect others associated with the case. This includes, but is not limited to: law enforcement agencies, medical examiners, coroners, the general public, family and friends of missing persons, family and friends of deceased persons, co-workers, classmates, concerned citizens, and the list can go on from there. By gaining more knowledge on clothed human remains and vulture scavenging patterns, all individuals involved can benefit from the more accurate scene interpretations, the more complete recovery of remains and other associated evidence (such as clothing or other personal effects), as well as a better understanding of the confounding factors when attempting to estimate the PMI.

Further studies should continue to compare clothed and unclothed individuals, with the goal of increasing the sample size to more accurately make generalizations for both clothed and unclothed human remains. Additionally, these further studies should include tracking the movement of the actual clothing as to better inform professionals on determining a more accurate search radius, as well as associating personal effects with the discovered individual. It may be important to note that conducting studies like these in populated/active research facilities may affect the outcome of these studies, as human disturbance or interference is likely to affect normal, candid feeding patterns of vultures (or any animal scavengers). Making efforts to control for this may also help to increase accuracy of results in such studies.

APPENDIX SECTION

Appendix A: Spatial Distribution Images for Clothed and Unclothed Subjects

Clothed Subjects

Table A1. This table is a legend that matches with the following plots for the clothed subjects. Each numbered data label corresponds with a major body part/area of the remains.

Data Label	Description
1	Top of Head
2	Chin
3	R Shoulder
4	L Shoulder
5	R Elbow
6	L Elbow
7	R Wrist
8	L Wrist
9	R Hip
10	L Hip
11	R Knee
12	L Knee

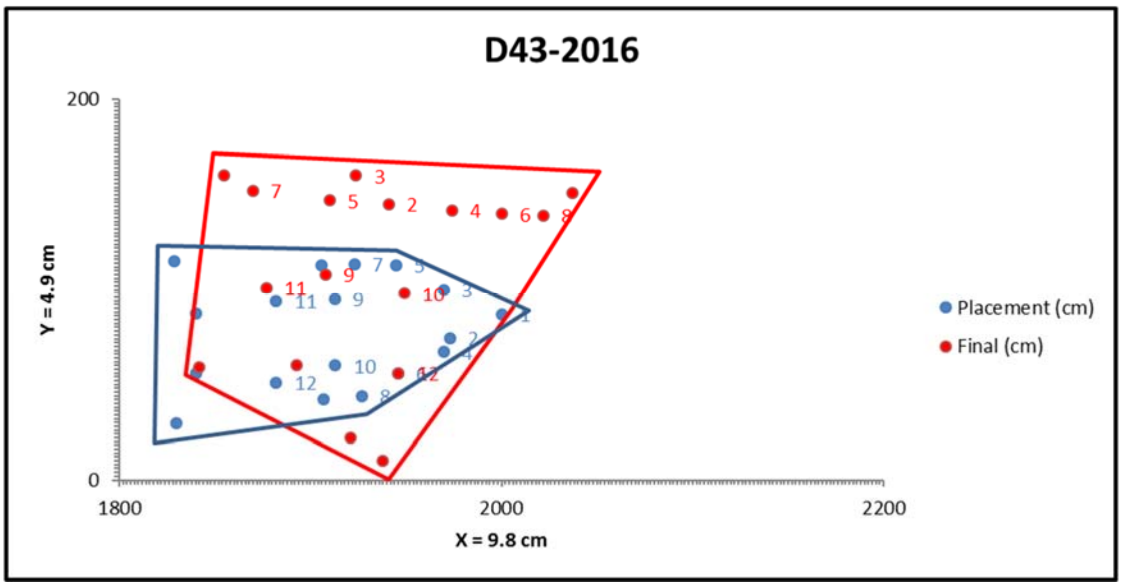

Figure A1. This figure shows a spatial distribution plot for clothed subject D43-2016. Blue dots represent anatomical landmarks taken at the time of placement. Red dots represent the distribution of the body at the end of the study period. Polygons are drawn around each set of points. Each data label is placed approximately 3 cm to the right of the data point. Note: Final data point 1 (top of head in red) is removed due to cranial autopsy.

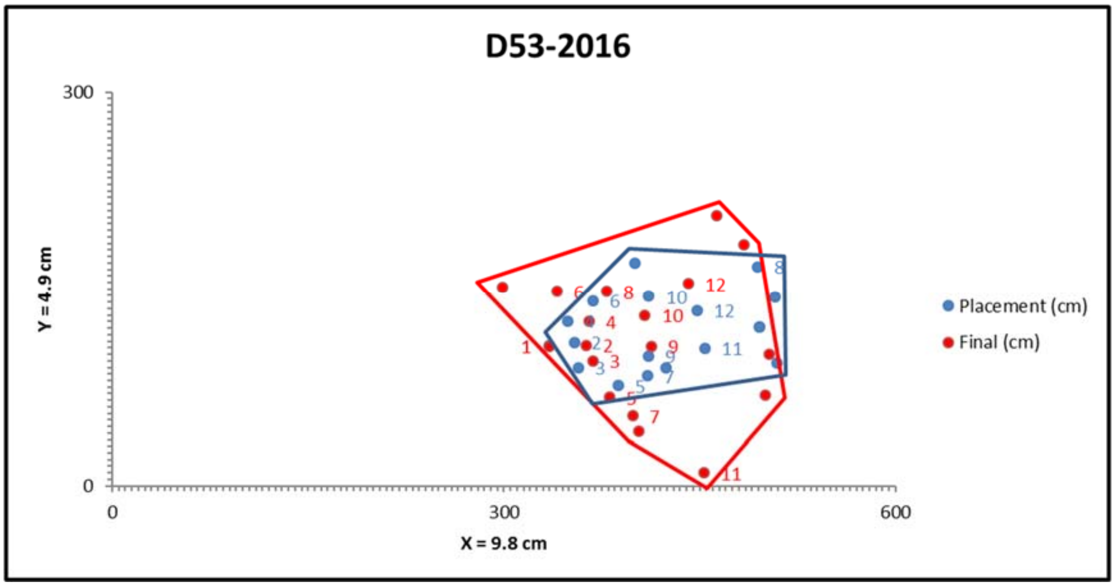

Figure A2. This figure shows a spatial distribution plot for clothed subject D53-2016. Blue dots represent anatomical landmarks taken at the time of placement. Red dots represent the distribution of the body at the end of the study period. Polygons are drawn around each set of points. Each data label is placed approximately 3 cm to the right of the data point.

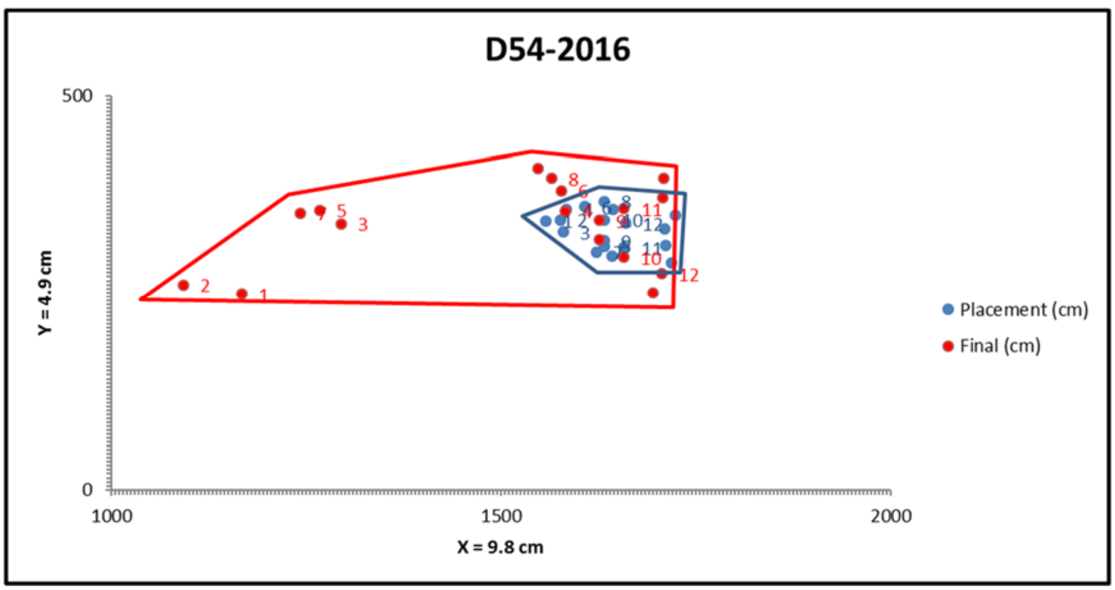

Figure A3. This figure shows a spatial distribution plot for clothed subject D54-2016. Blue dots represent anatomical landmarks taken at the time of placement. Red dots represent the distribution of the body at the end of the study period. Polygons are drawn around each set of points. Each data label is placed approximately 3 cm to the right of the data point.

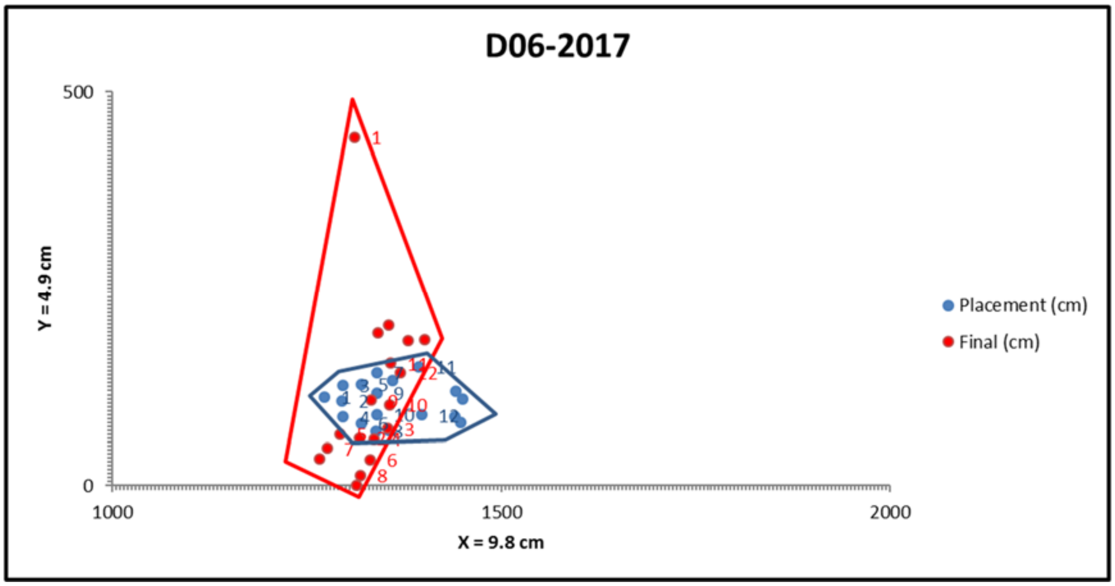

Figure A4. This figure shows a spatial distribution plot for clothed subject D06-2017. Blue dots represent anatomical landmarks taken at the time of placement. Red dots represent the distribution of the body at the end of the study period. Polygons are drawn around each set of points Each data label is placed approximately 3 cm to the right of the data point.

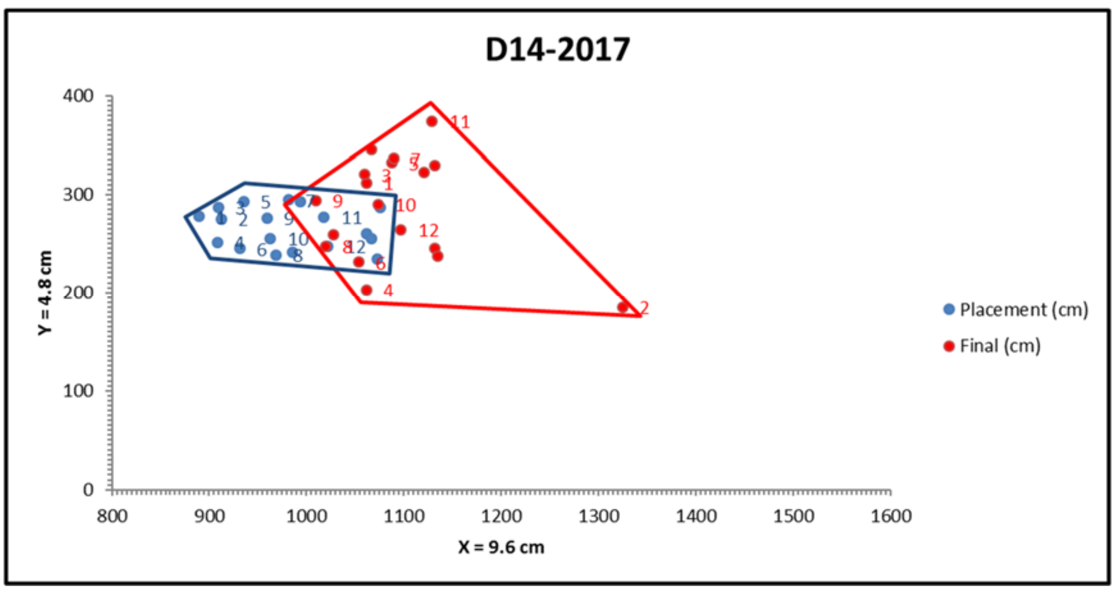

Figure A5. This figure shows a spatial distribution plot for clothed subject D14-2017. Blue dots represent anatomical landmarks taken at the time of placement. Red dots represent the distribution of the body at the end of the study period. Polygons are drawn around each set of points. Each data label is placed approximately 3 cm to the right of the data point.

Unclothed Subjects

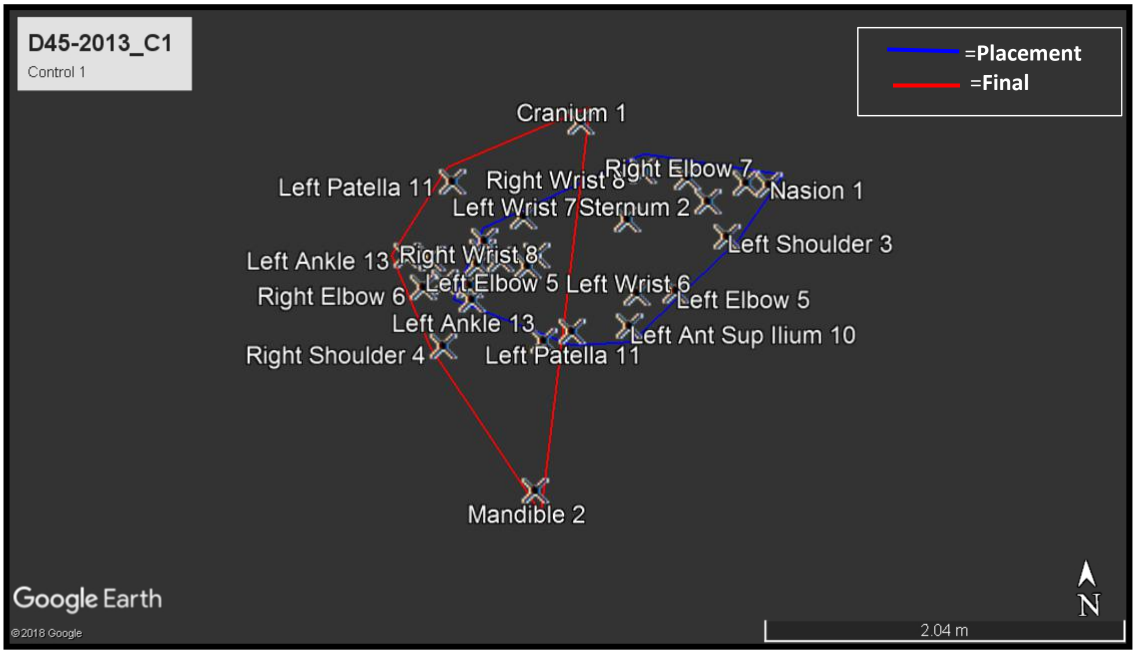

Figure A6. This figure shows a spatial distribution plot generated in Google Earth Pro for unclothed (control) subject D45-2013. Polygons are drawn around each set of points; the blue polygon and the red polygon represent placement and final locations respectively.

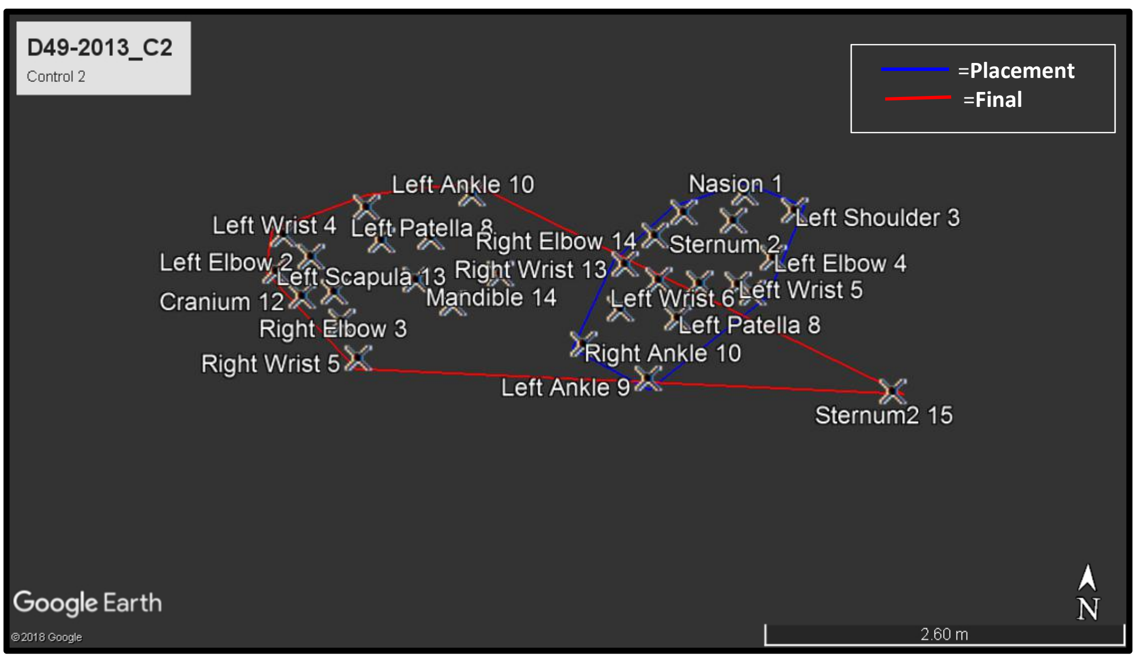

Figure A7. This figure shows a spatial distribution plot generated in Google Earth Pro for unclothed (control) subject D45-2013. Polygons are drawn around each set of points; the blue polygon and the red polygon represent placement and final locations respectively.

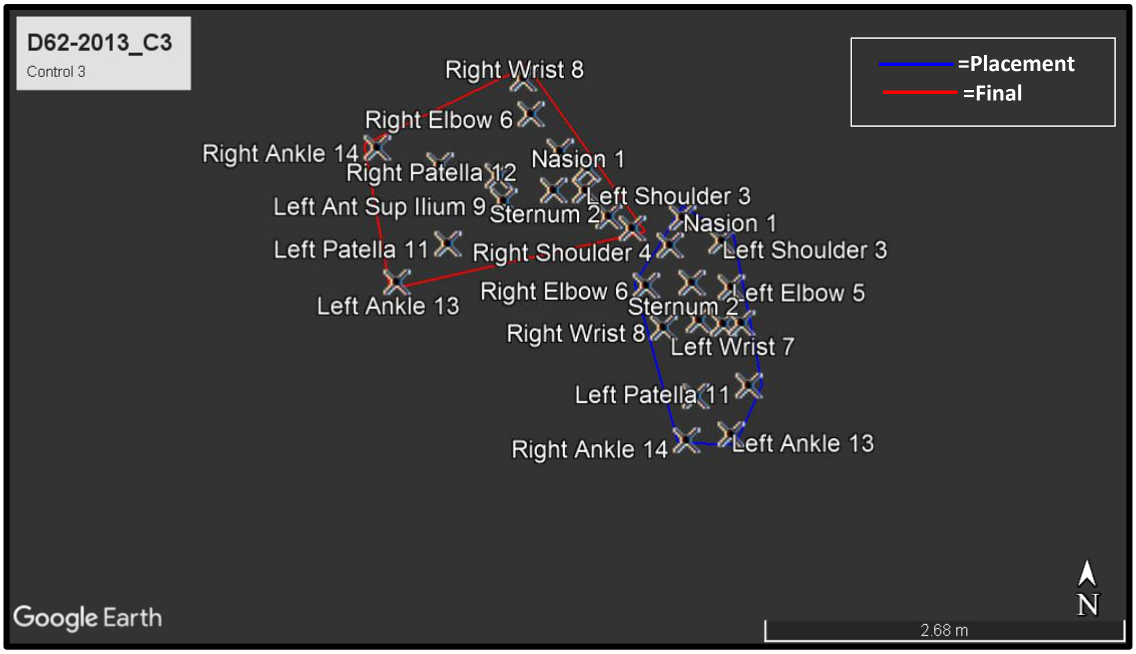

Figure A8. This figure shows a spatial distribution plot generated in Google Earth Pro for unclothed (control) subject D45-2013. Polygons are drawn around each set of points; the blue polygon and the red polygon represent placement and final locations respectively.

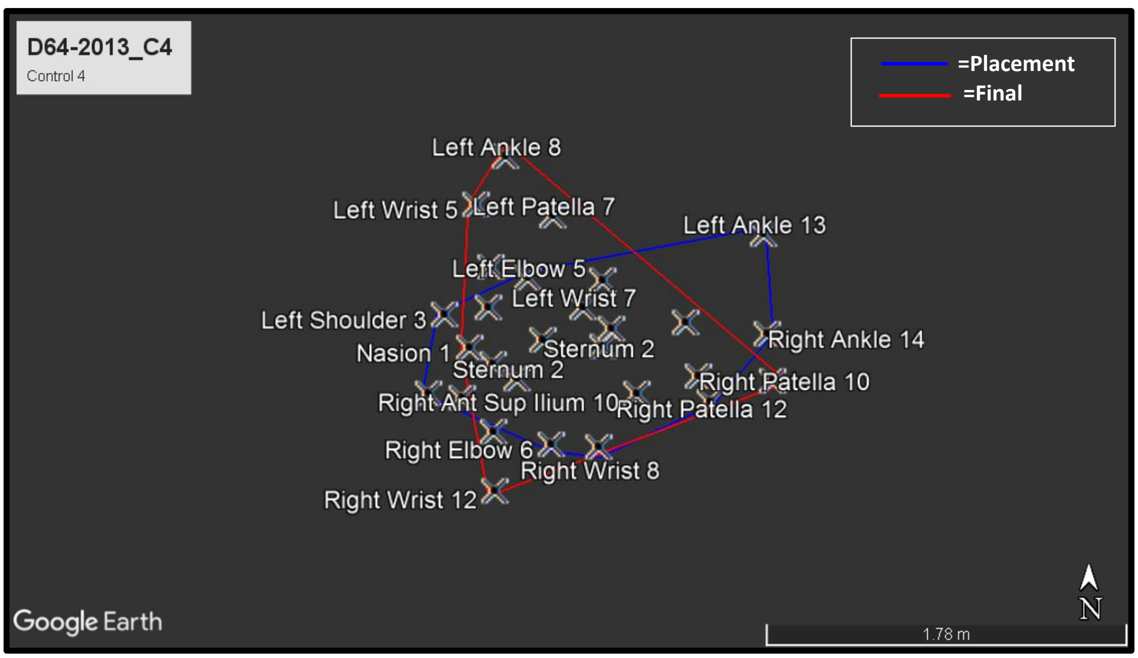

Figure A9. This figure shows a spatial distribution plot generated in Google Earth Pro for unclothed (control) subject D45-2013. Polygons are drawn around each set of points; the blue polygon and the red polygon represent placement and final locations respectively.

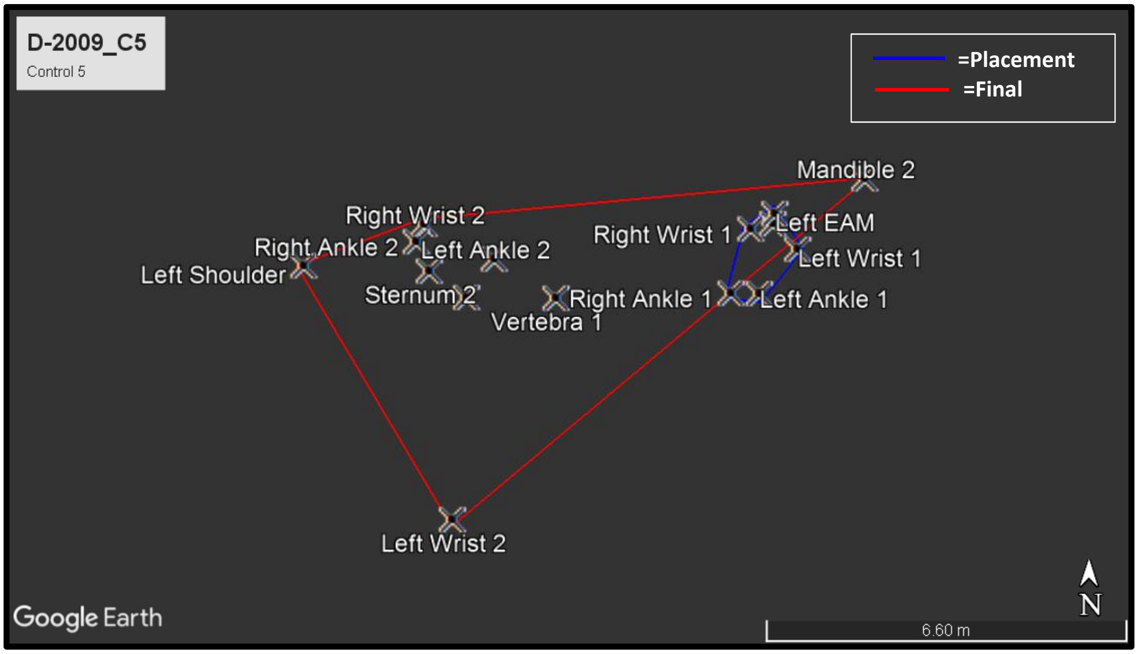

Figure A10. This figure shows a spatial distribution plot generated in Google Earth Pro for unclothed (control) subject D10-2009. Polygons are drawn around each set of points; the blue polygon and the red polygon represent placement and final locations respectively.

Appendix B: Placement and Final Aerial Drone Photos for Clothed Subjects

Figure B1. Aerial Photos Set 1. Placement (left) and final (right) drone aerial photos of clothed subject D43-2016.

Figure B2. Aerial Photos Set 2. Placement (left) and final (right) drone aerial photos of clothed subject D53-2016.

Figure B3. Aerial Photos Set 3. Placement (left) and final (right) drone aerial photos of clothed subject D54-2016.

Figure B4. Aerial Photos Set 4. Placement (left) and final (right) drone aerial photos of clothed subject D06-2017

Figure B5. Aerial Photos Set 5. Placement (left) and final (right) drone aerial photos of clothed subject D14-2017.

Appendix C: Weather, Known ADD, and TBS for Clothed Subjects

Table C1. Weather and ADD data for subject D43-2016.

Date	Max Temp (°C)	Min Temp (°C)	Daily ADD (°C)	Total ADD (°C)
9/24/2016	32	23	27.5	27.5
9/25/2016	31	22	26.5	54
9/26/2016	22	19	20.5	74.5
9/27/2016	24	19	21.5	96
9/28/2016	30	17	23.5	119.5
9/29/2016	29	14	21.5	141
9/30/2016	27	13	20	161
10/1/2016	27	13	20	181
10/2/2016	29	13	21	202
10/3/2016	30	15	22.5	224.5
10/4/2016	32	19	25.5	250
10/5/2016	33	21	27	277
10/6/2016	33	23	28	305
10/7/2016	30	18	24	329
10/8/2016	28	16	22	351
10/9/2016	28	14	21	372
10/10/2016	28	9	18.5	390.5
10/11/2016	30	10	20	410.5
10/12/2016	32	14	23	433.5
10/13/2016	31	21	26	459.5
10/14/2016	29	20	24.5	484
10/15/2016	32	20	26	510
10/16/2016	33	22	27.5	537.5
10/17/2016	33	22	27.5	565
10/18/2016	33	23	28	593
10/19/2016	33	22	27.5	620.5
10/20/2016	28	18	23	643.5
10/21/2016	24	9	16.5	660
10/22/2016	26	6	16	676
10/23/2016	29	9	19	695
10/24/2016	29	19	24	719
10/25/2016	28	16	22	741
10/26/2016	30	14	22	763
10/27/2016	30	15	22.5	785.5
10/28/2016	29	13	21	806.5
10/29/2016	29	14	21.5	828
10/30/2016	30	15	22.5	850.5
10/31/2016	28	13	20.5	871
11/1/2016	32	22	27	898
11/2/2016	31	23	27	925

11/3/2016	29	19	24	949
11/4/2016	23	20	21.5	970.5
11/5/2016	26	17	21.5	992
11/6/2016	25	16	20.5	1012.5
11/7/2016	24	16	20	1032.5
11/8/2016	21	17	19	1051.5
11/9/2016	18	16	17	1068.5
11/10/2016	21	12	16.5	1085
11/11/2016	23	12	17.5	1102.5
11/12/2016	23	12	17.5	1120
11/13/2016	23	13	18	1138
11/14/2016	26	11	18.5	1156.5
11/15/2016	29	12	20.5	1177
11/16/2016	29	10	19.5	1196.5
11/17/2016	28	12	20	1216.5
11/18/2016	26	11	18.5	1235

Table C2. Weather and ADD Data for subject D53-2016.

Date	Max Temp (°C)	Min Temp (°C)	Daily ADD (°C)	Total ADD (°C)
11/6/2016	25	16	20.5	20.5
11/7/2016	24	16	20	40.5
11/8/2016	21	17	19	59.5
11/9/2016	18	16	17	76.5
11/10/2016	21	12	16.5	93
11/11/2016	23	12	17.5	110.5
11/12/2016	23	12	17.5	128
11/13/2016	23	13	18	146
11/14/2016	26	11	18.5	164.5
11/15/2016	29	12	20.5	185
11/16/2016	29	10	19.5	204.5
11/17/2016	28	12	20	224.5
11/18/2016	26	11	18.5	243
11/19/2016	17	2	9.5	252.5
11/20/2016	19	0	9.5	262
11/21/2016	25	3	14	276
11/22/2016	25	15	20	296
11/23/2016	22	9	15.5	311.5
11/24/2016	23	6	14.5	326
11/25/2016	19	12	15.5	341.5
11/26/2016	21	12	16.5	358
11/27/2016	24	12	18	376
11/28/2016	27	9	18	394
11/29/2016	26	7	16.5	410.5
11/30/2016	19	3	11	421.5
12/1/2016	21	1	11	432.5

12/2/2016	17	11	14	446.5
12/3/2016	16	10	13	459.5
12/4/2016	11	9	10	469.5
12/5/2016	12	8	10	479.5
12/6/2016	17	6	11.5	491
12/7/2016	12	4	8	499
12/8/2016	11	2	6.5	505.5
12/9/2016	7	1	4	511
12/10/2016	11	0	5.5	519
12/11/2016	16	10	13	532
12/12/2016	19	8	13.5	545.5
12/13/2016	24	10	17	562.5
12/14/2016	12	7	9.5	572
12/15/2016	13	8	10.5	582.5
12/16/2016	17	11	14	596.5
12/17/2016	24	3	13.5	610
12/18/2016	3	0	1.5	611.5
12/19/2016	8	0	4	615.5
12/20/2016	14	2	8	623.5
12/21/2016	21	4	12.5	636
12/22/2016	19	8	13.5	649.5
12/23/2016	22	12	17	666.5
12/24/2016	24	19	21.5	688
12/25/2016	26	19	22.5	710.5
12/26/2016	29	19	24	734.5
12/27/2016	24	17	20.5	755
12/28/2016	28	17	22.5	777.5
12/29/2016	19	9	14	791.5
12/30/2016	13	8	10.5	802
12/31/2016	23	10	16.5	818.5
1/1/2017	23	11	17	835.5
½/2017	25	8	16.5	846
1/3/2017	26	6	16	850.5
¼/2017	9	3	6	853.5
1/5/2017	18	3	10.5	868
1/6/2017	2	0	1	868.5
1/7/2017	6	0	3	882
1/8/2017	12	0	6	893
1/9/2017	22	5	13.5	907
1/10/2017	27	12	19.5	917
1/11/2017	26	12	19	922
1/12/2017	27	18	22.5	938.5
1/13/2017	26	16	21	950.5
1/14/2017	16	10	13	959.5
1/15/2017	23	11	17	973
1/16/2017	19	14	16.5	983

1/17/2017	14	9	11.5	992
1/18/2017	14	8	11	1005
1/19/2017	20	9	14.5	1010
1/20/2017	23	8	15.5	1015
1/21/2017	28	9	18.5	1026
1/22/2017	20	7	13.5	1033.5
1/23/2017	24	4	14	1047.5
1/24/2017	29	6	17.5	1072.5
1/25/2017	21	8	14.5	1097.5
1/26/2017	14	2	8	1110.5
1/27/2017	13	2	7.5	1134
1/28/2017	17	2	9.5	1156.5

Table C3. Weather and ADD data for subject D54-2016.

Date	**Max Temp (°C)**	**Min Temp (°C)**	**Daily ADD (°C)**	**Total ADD (°C)**
11/19/2016	17	2	9.5	9.5
11/20/2016	19	0	9.5	19
11/21/2016	25	3	14	33
11/22/2016	25	15	20	53
11/23/2016	22	9	15.5	68.5
11/24/2016	23	6	14.5	83
11/25/2016	19	12	15.5	98.5
11/26/2016	21	12	16.5	115
11/27/2016	24	12	18	133
11/28/2016	27	9	18	151
11/29/2016	26	7	16.5	167.5
11/30/2016	19	3	11	178.5
12/1/2016	21	1	11	189.5
12/2/2016	17	11	14	203.5
12/3/2016	16	10	13	216.5
12/4/2016	11	9	10	226.5
12/5/2016	12	8	10	236.5
12/6/2016	17	6	11.5	248
12/7/2016	12	4	8	256
12/8/2016	11	2	6.5	262.5
12/9/2016	7	1	4	266.5
12/10/2016	11	0	5.5	272
12/11/2016	16	10	13	285
12/12/2016	19	8	13.5	298.5
12/13/2016	24	10	17	315.5
12/14/2016	12	7	9.5	325
12/15/2016	13	8	10.5	335.5
12/16/2016	17	11	14	349.5
12/17/2016	24	3	13.5	363
12/18/2016	3	0	1.5	364.5

12/19/2016	8	0	4	368.5
12/20/2016	14	2	8	376.5
12/21/2016	21	4	12.5	389
12/22/2016	19	8	13.5	402.5
12/23/2016	22	12	17	419.5
12/24/2016	24	19	21.5	441
12/25/2016	26	19	22.5	463.5
12/26/2016	29	19	24	487.5
12/27/2016	24	17	20.5	508
12/28/2016	28	17	22.5	530.5
12/29/2016	19	9	14	544.5
12/30/2016	13	8	10.5	555
12/31/2016	23	10	16.5	571.5
1/1/2017	23	11	17	588.5
½/2017	25	8	16.5	605
1/3/2017	26	6	16	621
¼/2017	9	3	6	627
1/5/2017	18	3	10.5	637.5
1/6/2017	2	0	1	638.5
1/7/2017	6	0	3	641.5
1/8/2017	12	0	6	647.5
1/9/2017	22	5	13.5	661
1/10/2017	27	12	19.5	680.5
1/11/2017	26	12	19	699.5
1/12/2017	27	18	22.5	722
1/13/2017	26	16	21	743
1/14/2017	16	10	13	756
1/15/2017	23	11	17	773
1/16/2017	19	14	16.5	789.5
1/17/2017	14	9	11.5	801
1/18/2017	14	8	11	812
1/19/2017	20	9	14.5	826.5
1/20/2017	23	8	15.5	842
1/21/2017	28	9	18.5	860.5
1/22/2017	20	7	13.5	874
1/23/2017	24	4	14	888
1/24/2017	29	6	17.5	905.5
1/25/2017	21	8	14.5	920
1/26/2017	14	2	8	928
1/27/2017	13	2	7.5	935.5
1/28/2017	17	2	9.5	945

Table C4. Weather and ADD data for subject D06-2017.

Date	Max Temp (°C)	Min Temp (°C)	Daily ADD (°C)	Total ADD (°C)
1/28/2017	17	2	9.5	9.5
1/29/2017	21	0	10.5	20
1/30/2017	26	3	14.5	34.5
1/31/2017	25	3	14	48.5
2/1/2017	27	4	15.5	64
2/2/2017	16	8	12	76
2/3/2017	12	7	9.5	85.5
2/4/2017	11	8	9.5	95
2/5/2017	22	11	16.5	111.5
2/6/2017	26	19	22.5	134
2/7/2017	31	12	21.5	155.5
2/8/2017	31	8	19.5	175
2/9/2017	20	7	13.5	188.5
2/10/2017	26	6	16	204.5
2/11/2017	30	18	24	228.5
2/12/2017	29	14	21.5	250
2/13/2017	26	16	21	271
2/14/2017	19	9	14	285
2/15/2017	18	4	11	296
2/16/2017	19	1	10	306
2/17/2017	25	7	16	322
2/18/2017	29	16	22.5	344.5
2/19/2017	27	15	21	365.5
2/20/2017	21	13	17	382.5
2/21/2017	26	10	18	400.5
2/22/2017	30	7	18.5	419
2/23/2017	32	10	21	440
2/24/2017	28	11	19.5	459.5
2/25/2017	17	7	12	471.5
2/26/2017	21	3	12	483.5
2/27/2017	28	18	23	506.5
2/28/2017	27	17	22	528.5
3/1/2017	24	12	18	546.5
3/2/2017	19	6	12.5	559
3/3/2017	19	5	12	571
¾/2017	15	13	14	585
3/5/2017	23	14	18.5	603.5
3/6/2017	28	19	23.5	627
3/7/2017	23	14	18.5	645.5
3/8/2017	23	14	18.5	664
3/9/2017	27	18	22.5	686.5
3/10/2017	26	16	21	707.5
3/11/2017	19	16	17.5	725

3/12/2017	17	8	12.5	737.5
3/13/2017	19	9	14	751.5
3/14/2017	23	4	13.5	765
3/15/2017	24	6	15	780
3/16/2017	27	14	20.5	800.5
3/17/2017	29	17	23	823.5
3/18/2017	28	14	21	844.5
3/19/2017	29	17	23	867.5
3/20/2017	29	18	23.5	891
3/21/2017	29	14	21.5	912.5

Table C5. Weather and ADD data for subject D14-2017.

Date	Max Temp (°C)	Min Temp (°C)	Daily ADD (°C)	Total ADD (°C)
3/21/2017	29	14	21.5	21.5
3/22/2017	28	18	23	44.5
3/23/2017	29	18	23.5	68
3/24/2017	28	16	22	90
3/25/2017	28	9	18.5	108.5
3/26/2017	30	14	22	130.5
3/27/2017	29	19	24	154.5
3/28/2017	28	16	22	176.5
3/29/2017	29	15	22	198.5
3/30/2017	27	10	18.5	217
3/31/2017	30	11	20.5	237.5
4/1/2017	27	18	22.5	260
4/2/2017	26	14	20	280
4/3/2017	29	10	19.5	299.5
4/4/2017	31	12	21.5	321
4/5/2017	23	10	16.5	337.5
4/6/2017	24	6	15	352.5
4/7/2017	26	8	17	369.5
4/8/2017	27	11	19	388.5
4/9/2017	27	17	22	410.5
4/10/2017	27	21	24	434.5
4/11/2017	22	16	19	453.5
4/12/2017	26	16	21	474.5
4/13/2017	29	18	23.5	498
4/14/2017	28	16	22	520
4/15/2017	29	19	24	544
4/16/2017	29	19	24	568
4/17/2017	27	17	22	590
4/18/2017	27	14	20.5	610.5
4/19/2017	28	19	23.5	634
4/20/2017	30	20	25	659
4/21/2017	31	21	26	685

4/22/2017	22	16	19	704
4/23/2017	24	10	17	721
4/24/2017	27	8	17.5	738.5
4/25/2017	32	15	23.5	762
4/26/2017	33	17	25	787
4/27/2017	28	9	18.5	805.5
4/28/2017	34	21	27.5	833

Table C6. TBS scores for head (H), trunk (T), and limbs (L).

Date	H	T	L	TBS
11/17/2016	12	8	8	28
1/28/2017	11	8	7	26
1/28/2017	11	8	8	27
3/21/2017	11	8	7.5	26.5
4/28/2017	11	10	8.5	29.5

Table C7. Known and estimated ADD/PMI breakdown.

Est. ADD	Known ADD	Estimated PMI[1]	Placement Date	Difference (days)
2387.8	1235	8/18/2016	9/24/2016	37
1452.1	1188	10/25/2016	11/6/2016	12
2719.6	945	9/4/2016	11/19/2017	76
1638.7	912.5	12/3/2017	1/28/2017	56
3552.22	833	10/13/2016	3/21/2017	160

[1]Based on TBS in Megyesi et al. (2005) equation. The standard error provided is 388.16 ADD.

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