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Spatial patterning of vulture scavenged human remains

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ABSTRACT

This article presents the results of a pilot study on the effects of vulture modification to human remains. A donated body from the Willed Body Donation Program was placed at the Forensic Anthropology Research Facility (FARF), an outdoor human decomposition laboratory located at Texas State University-San Marcos. The effects of vulture scavenging on the timing and sequence, and the rate of skeletonization, disarticulation, and dispersal were observed via a motion sensing camera and direct observation. Using GIS (Geographic Information Systems) and GPS (Global Positioning System) technologies and spatial analytical methods, the transport of skeletal elements was mapped in order to analyze dispersal and terrain-influenced patterns of active vulture scavenging. Results showed that the initial scavenging took place 37 days after placement at FARF. This delay in scavenging differs from previous research [1]. After the initial appearance of the vultures, the body was reduced from a fully-fleshed individual to a skeleton within only 5 h. This underscores the potential for errors in postmortem interval estimations made at vulture scavenged scenes. Additionally, spatial analysis showed that skeletal elements were dispersed by vultures to lower elevations, and that the disarticulation and dispersal of the skeletal elements occurs early in the scavenging sequence.

1. Introduction

When investigators are tasked with identifying decomposing or skeletonized human remains, the forensic anthropologist can offer critical assistance by developing the biological profile—assessing age, sex, ancestry, and stature—and by rendering estimates of factors such as the postmortem interval (PMI) or time since death. The PMI is an important criterion because it provides law enforcement with a temporal restraint to narrow the list of possible missing persons, or it may assist in establishing suspected perpetrator chronologies. Estimating time since death, already a complex undertaking due to the number of variables involved with soft tissue decomposition and bone breakdown, becomes more difficult when animal scavengers have modified the remains.

Recent literature concerning estimations of time since death is derived from cross-sectional studies using case studies from medical examiner's offices i.e. [2] or longitudinal data using animal models i.e. [3]. Both types of studies are valuable contributions to estimates of time since death, however using cross-sectional case studies provides only the end result of the decomposition process, and not a means to understand the sequence of events that results in the decomposition and disarticulation stage at the time of discovery. Much of the literature highlighting the importance of scavenger activity in decompositional studies has been in the form of cross-sectional decomposition studies i.e. [2,4–7] which involve reviews of medical examiner or coroner case reports, and do not have the ability to control for scavenger species, appearance, or behavior.

Active research has suggested that certain types of animal scavenging can increase the rate of decomposition. Using pigs as human models, Morton and Lord [8] reported on the timing and sequence of multiple scavengers attracted to child-sized pig carcasses. However, carcass size has been reported to influence decomposition rates [9], therefore animal models may not provide accurate or comparative results to human models in many cases.

Thus far, much of the published forensic taphonomic research has been of limited comparative or testable value, and the critical need exists for the development and standardization of taphonomically based PMI estimation techniques using human remains versus animal models to examine the degree of influence animal scavengers have on the decomposition sequence of human bodies. One promising area of research that may prove useful data but that requires more rigorous exploration is the timing and signature of specific animal scavengers, and how their activities and interactions with human bodies may better inform estimations of time since death.

Scavengers significantly alter the condition and decomposition rate of a human body, and several publications have highlighted that these taphonomic indicators can help to better interpret

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postmortem events and the postmortem interval i.e. [4,7,10,11]. Examining rodent gnawing, Klippel and Synstelien [10] found that rat and squirrel modification to bone can be used to establish minimum postmortem intervals. Actualistic research and case studies interpreting canid modification have also proven useful for estimation of the postmortem interval, demonstrating that feeding and disarticulation proceeds along a temporal continuum [4,11–14]. Additionally, these canid studies have identified the spatial distribution pattern of carnivore disarticulation and skeletal element dispersal, suggesting search and recovery strategies for canid-scavenged death scenes.

Avian scavenging is a largely unexplored phenomenon, and is largely restricted to discussions of the effects of crow scavenging [1,15,16]. Reeves [1] examined the timing and patterning of vulture scavenging using pig models, and found that both American black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*) waited approximately 24 h from the point of deposition before they began to scavenge the remains. They completely skeletonized the 60–100 pound (27–63 kg) carcasses in roughly 4 h of feeding. The effects of vulture scavenging on human remains and their corresponding modification of the decomposition and skeletonization sequence of human remains are anecdotally appreciated, but have not yet been addressed in the literature or via research.

Various vulture species occur world-wide and occupy a dominant carrion scavenger ecological niche, with ranges spanning from portions of Canada to South America [17–19]. Vultures are carrion scavengers with specialized features including large wingspans, energy-conserving soaring behaviors, superior eyesight and/or olfactory abilities, and reduction of feathers around the head that allow them to outcompete other scavengers by locating and consuming carrion more rapidly [20–23].

Black vultures have a preference for open areas such as pastures and fields for foraging, but they are also closely linked to urban development, and can be found in the vicinity of markets and other city feeding areas [21,24]. The black vulture, in particular, is often found in association with populated habitation areas, feeding on human refuse [24]. Turkey vultures tend to inhabit a variety of environments such as grasslands, deserts, and temperate woodlands [18]. In combination, black vultures and turkey vultures inhabit almost every state in the continental United States either permanently or seasonally [25,26], and any human body deposited in an outdoor setting may be subject to abnormal decomposition and skeletonization rates as a result of their scavenging activities.

The purpose of this paper is to report on a longitudinal case study that is part of on-going research examining vulture modification to human remains. The ultimate goals of the project will be to establish vulture modified decomposition sequences, differentiate vulture-caused trauma that may be mistaken for perimortem trauma, and identify skeletal disarticulation patterns at vulture scavenged scenes using GIS (Geographic Information Systems) and spatial analytical methods. This short technical report represents the first phase of this research project, which systematically documents the sequence of vulture consumption, disarticulation, and transport of fleshed and skeletonized human remains.

2. Materials and methods

The Forensic Anthropology Research Facility (FARF) is a 20+ acre outdoor human decomposition facility with an active anatomical Willed Body Donation Program at Texas State University-San Marcos. Currently, 5 acres are fenced with reinforced chain linking to prevent terrestrial scavengers from entering the facility, although avian scavengers have unrestricted and open access. FARF is located within Freeman Ranch, a 4204 acre working agricultural ranch owned by Texas State located in the Edwards plateau ecological region of Texas [27]. The land occupied by FARF is characterized by grassland with tree clusters, predominantly live oak with cedar and juniper trees [27]. The ranch has a mean annual temperature of 60 °F (16 °C) with summer highs of 90+ °F and lows of 40 °F (32+ to 4 °C) during winter months, with every month except December and January having recorded highs of 90+ °F [28].

On November 19, 2009, a donated human body from the Willed Body Donation Program at Texas State University-San Marcos was placed at FARF. The adult female was in a fresh (non-decomposed) state, was un-autopsied, and had died of natural causes. A motion sensing infra-red game camera (*Moultrie Game Spy*®) was positioned adjacent to the body in order to capture episodes of animal activity. Based on previous observations at FARF, vultures were seen disarticulating and scattering human remains, therefore mapping strategies were employed to determine whether there was an identifiable disarticulation sequence and pattern to vulture scavenging.

Global Positioning System (GPS) technologies were employed to track the disarticulation and spread of the scavenged remains, and a GIS database was created to help map and organize the data collected in the field. The data were analyzed using spatial analytical methods to detect patterns in the movement, transport, and scattering of body parts as a result of vulture scavenging.

GPS is employed to determine the exact location of an object (e.g., a body or skeletal element) within the framework of a coordinate system (usually, latitude and longitude). All positional measurements thus acquired carry a measurable degree of horizontal and vertical positional accuracy. In the Geographic Information Science (GIScience) context, accuracy is defined as the closeness of a measurement to its true value, and the term positional accuracy is used to describe the accuracy of the positional measurement. In the context of this specific project, positional accuracy is a key issue. Because scavenging by vultures may move body parts only a few decimeters or meters at a time, it follows that the positional accuracy of the GPS measurements must be very high in order for the spatial patterns identified during the analytical stage to be reliable. The objective can be accomplished using a variety of GPS and GIS hardware and software configurations. In this pilot-project, we employed GPS hardware (Trimble's *GeoExplorer XT*®) capable of acquiring carrier-phase data and GPS software (Trimble's *Pathfinder Office*®) for post-processing differential correction. The acquisition of carrier-phase data is not without obstacles; the surveyor must have a clear, unobstructed, uninterrupted, and geometrically optimal view of the location of the satellites in the sky for a considerable amount of time in order to be able to achieve positional accuracy values in the desired range. In addition to optimal external environmental conditions, differential GPS requires the presence of a nearby base station, necessary in the post-processing stage to differentially correct the carrier phase data collected in the field. Although base stations can be set up and managed—at considerable cost—by the researcher, in our case we were fortunate to be able to use data from publicly owned and managed base stations located in the vicinity of FARF. Two base stations are located within 7 miles: one (TX-DOT San Marcos) is operated by the Texas Department of Transportation and the other, CORS-San Marcos (*Continuously Operated Reference Station*) is managed by the National Geodetic Survey of the National Oceanic and Atmospheric Administration (NOAA). The CORS station is particularly reliable and was used to differentially correct all GPS data collected for the project.

On November 23, 2009 (4 days after initial placement of the donor's body) the primary location of the cadaver was mapped using a *GeoExplorer XT*®. There was no disturbance of the body between the date of placement and the first mapping session. The points surveyed represent the orientation of the body and rough approximate skeletal landmarks (external auditory meatus or ear canal, inferior sternum, left and right wrist, and left and right ankle). The body was observed daily and the camera monitored daily for signs of vulture modification. Once the body was disturbed by vultures, the remains were again mapped to track the levels of disturbance and degree of disarticulation. Surveys were conducted of vulture disturbance episodes on January 10, January 18, March 7, and June 10 (final survey) of 2010.

3. Results

3.1. Vulture scavenging observations

Within the first week of placement, two black vultures were captured on camera damaging the soft tissue of the eyes. Over the next 30+ days, as verified by camera and field observations, no additional vultures or other animal agents showed any interest in the body (with the exception of maggots, which were limited to the facial orifices and to the ground–body interface area). Due to cold temperatures, the body remained in a fairly fresh state from time of placement, with discoloration, slight bloating, and minimal skin slippage present until December 26, 2009, just over one month from the initial placement of the donor's body at FARF. Because decomposition is largely dependent on temperature, and temperature varies in different geographic regions, accumulated degree days (ADD) were calculated from time of placement until skeletonization by vultures.

Fig. 1. Vulture scavenging sequence on donated human remains at the Forensic Anthropology Research Facility in San Marcos, Texas (December 26–27, 2009). (A) Fully fleshed body with the first appearance of an American black vulture at 11:16 am. (B) Approximately 1 h later, multiple vultures present and feeding. (C) Four hours later, all viscera and much soft tissue have been removed. (D) By December 27 at 12:12 pm (approximately 24 h after picture (A)), the body is largely skeletonized, and vultures have modified the orientation and positioning. Over the next 48 h, they will continue to drag the body out of camera range.

In order to calculate ADD, daily air temperature was obtained from a weather station owned by Texas A&M located on Freeman Ranch [29]. When calculating ADD, negative temperatures are truncated at 0, the temperature reported to significantly slow the decomposition process [30]. In this particular case, the ADD was 247.75 prior to skeletonization by vultures. The average (actual) daily high from the day after placement of the donation through December 26, was 11.39 °C and the average low 2 °C (using 0° as the lower limit).

This episode of vulture activity occurred mid-morning on December 26th, when multitudes of black vultures suddenly appeared in large numbers (over 30 counted in some frames) to scavenge the body. The vultures removed the majority of all soft tissue, rendering a body that was whole and fully fleshed into a skeleton in only ~5 h of active feeding over a 24 h period (Fig. 1). The vultures continued to return to the skeletonized body for approximately 15 weeks afterwards, disarticulating and scattering specific skeletal elements from the location of primary deposition. Note that in addition to the black vultures, other avian species including turkey vultures, red-tailed hawks (*Buteo jamaicensis*), and crested caracaras (*Caracara cheriway*) were intermittently captured on camera appearing to investigate the body. Turkey vultures appeared on camera investigating the body, but then left with the arrival of a large flock of black vultures, the red-tailed hawk appeared on two occasions standing on the body, but then left with the arrival of black vultures, and the caracara appeared once but did not appear to scavenge from the body. No other avian or terrestrial scavengers were captured by the motion sensing camera, thus all the damage to the skeletal remains is attributed to the actions of black vultures.

3.2. Mapping and analysis of data

The data collected in the field were mapped and analyzed using ESRI *ArcGIS* 9.3. Fig. 2 shows the initial location of the body when it was first mapped on November 23, 2009 (triangles) and four successive displacements of the remains after the December 26th episode of vulture scavenging. A series of descriptive spatial analytical and spatial statistics measures were taken to summarize spatial patterns in the displacement. In addition, we measured the elevation of all the forty-nine GPS locations to create a 3D model of the area under study (see contour representation in Figs. 2–4).

Overall, the body was displaced across an area of less than 83.6 square meters (900 square feet) and spread from higher elevations to lower elevations: the highest was 259 m (849.6 feet) for the left ear canal on November 23, 2009; the lowest was 257 m (844.2 feet) for the left femur on June 10, 2010. These two body parts are also the farthest away from each other, with a measured distance of 15.8 m (51.7 feet). Spatial patterns of displacement, in both distance and direction, vary for different body parts. Figs. 2 and 3 and Table 1 provide a visual and tabular summary of the patterns. It is especially interesting to follow the scavenging patterns of the eight distinct body parts (see Table 1) that were repeatedly moved by vultures. As is to be expected, the body was moved across the largest distances between November 23, 2009 and January 10, 2010, a temporal interval that corresponds to the most intense periods of scavenging activity. In general, the longer the time between surveys, the longer the distance of dispersion by vultures.

The left shoulder (represented by the scapula, humerus, radius, and ulna) and the left wrist were moved the farthest from the original deposition of the body. It is interesting to note that the remains mapped on January 10 were in the skeletal stage; however some tendons and ligaments were still in place articulating the bones together. It appears that the vultures returned to the site and relocated the skeletal remains with no flesh remaining to consume. The remains of the individual are still located at FARF and have not been disturbed (relocated) by vultures or any other type of

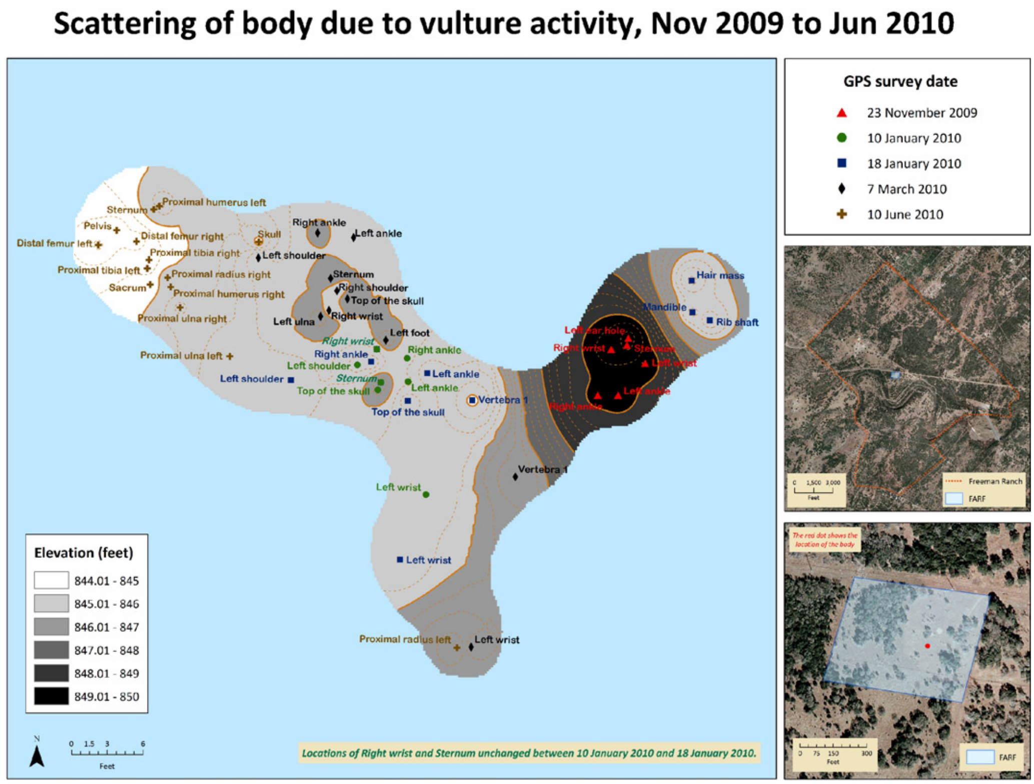

Fig. 2. Main map: location of donor's body parts at various dates, with elevation. Locator maps: the Forensic Anthropology Research Facility (FARF) within the Freeman Ranch (right middle) and approximate location of the body within FARF (right bottom).

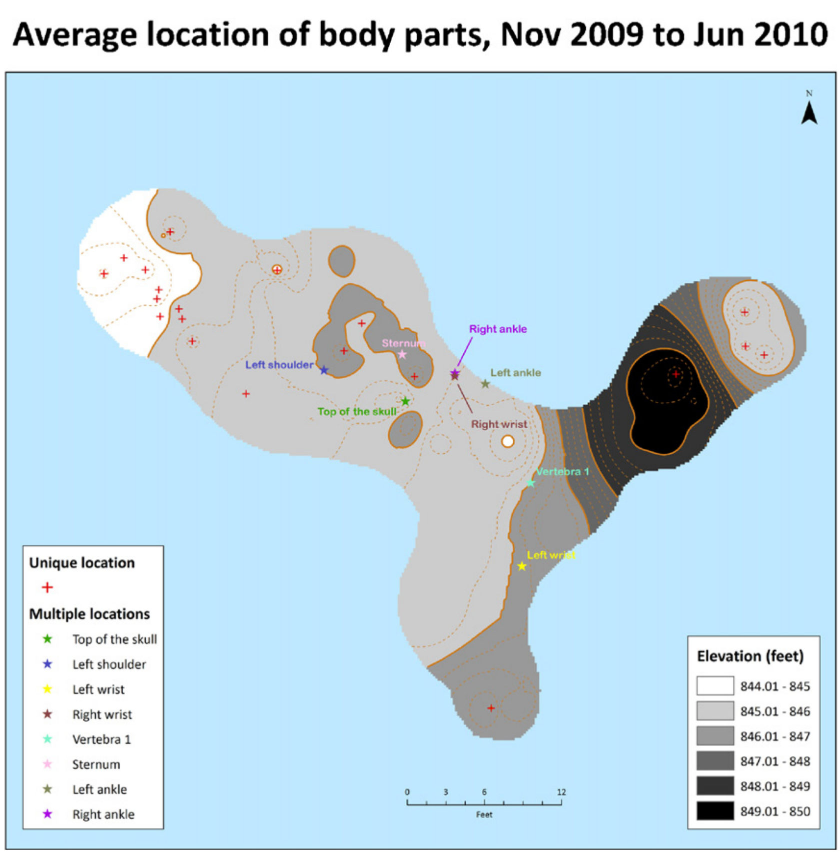

Fig. 3. This map shows the location of body parts that were surveyed only once (unique location) and the average geographical location of body parts that were displaced during the scavenging process (multiple locations).

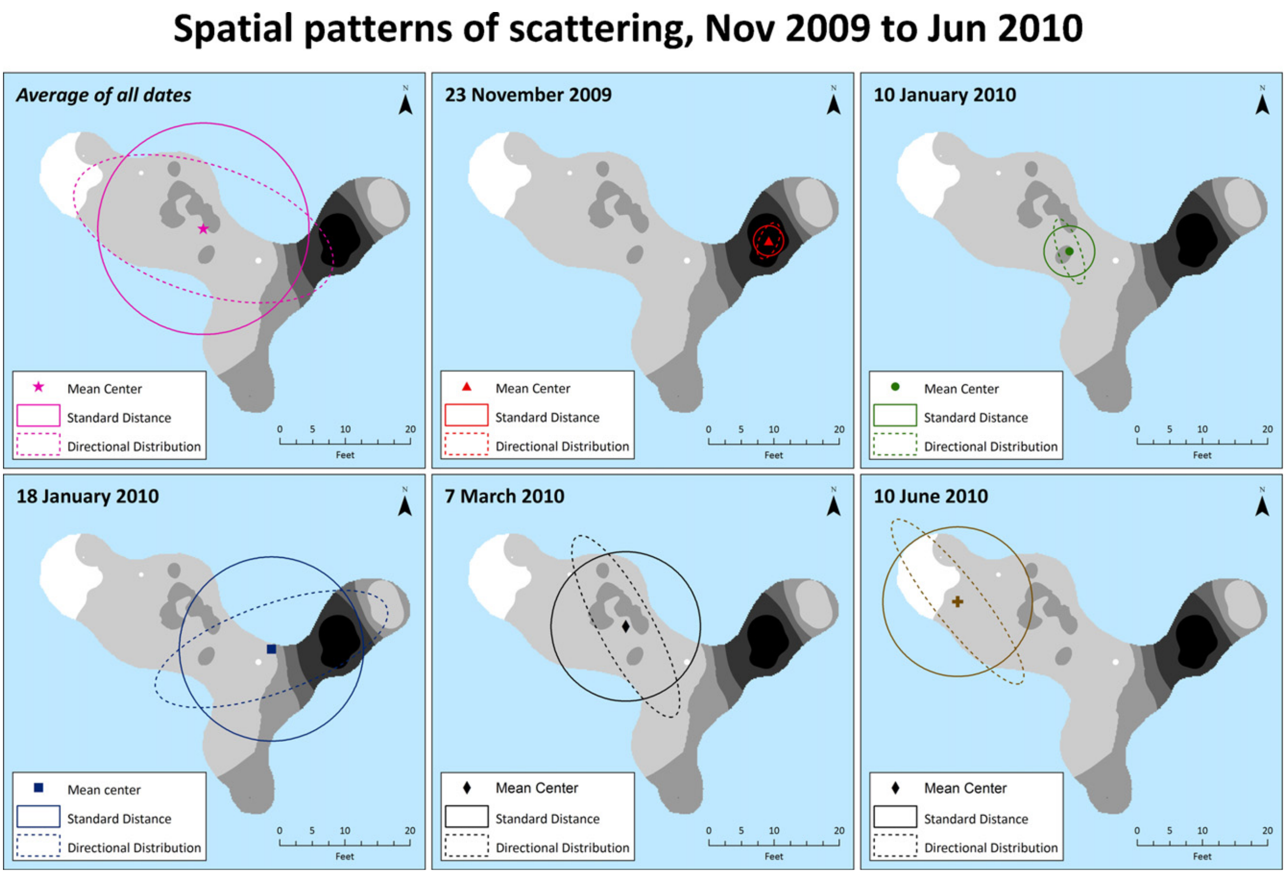

Fig. 4. Spatial analytical measures: Mean Center, Standard Distance, and Directional Distribution at different dates.

scavenger. At the time of this writing (mid-2011), the location of the remains has not changed.

In addition to the summary descriptive patterns briefly discussed above, we also conducted more sophisticated spatial analysis of the GPS survey in order to better delineate basic patterns in the scattering of human remains by vultures. Fig. 4, top left shows the location of the Mean Center, and the extent and direction of the Directional Distribution and Standard Distance for all the data surveyed, at different dates. Together, these three measures provide a basic picture of the scavenging events. The Mean Center is a point that identifies the geographic center of a set of locations and is calculated as the average of the x and y coordinates of all the features in the study area; the measure is useful for tracking changes in the distribution of a certain feature, or for comparing the distributions of different types of features. The Standard Distance is a circle that measures the degree of dispersion or concentration of the features mapped around the Mean Center; the measure is a geographical correspondent to the standard deviation. Finally, the Directional Distribution (also called the Standard Deviational Ellipse) measures the directional trend of a set of features, calculated by determining the value of the Standard Distance separately in the x and y directions; the resulting ellipse shows the degree of elongation and the orientation existing in the spatial distribution of the features studied.

Fig. 4 shows six maps—one per date of survey plus a summary for all dates—that together provide a summary of the spatial patterns of scattering. The initial November 23, 2009 spatial patterns show a high degree of concentration (small Standard Distance circle) around the Mean Center and a general southeast-to-northwest orientation of the body (shape of the Directional Distribution ellipse). The first major episode of scavenging results in the displacement of the body by an average of approximately 5.47 m (18 feet) to the west and at a lower elevation; although the general direction of the body has shifted to a southeast-to-northwest direction, the degree of spatial concentration is still

Table 1
Scattering distances (in feet) between successive GPS surveys. The table only shows body parts whose location varied at different dates.

Body parts	Dates and scattering distance from primary deposition			
	23-November-09 to 10-January-10	10-January-10 to 18-January-10	18-January-10 to 7-March-10	7-March-10 to 10-June-10
Left ankle	17.6	1.8	13.0	NA
Left shoulder	NA	5.7	10.6	NA
Left wrist	21.4	5.9	9.5	NA
Right ankle	16.3	3.0	11.7	NA
Right wrist	19.7	0.0	5.2	NA
Sternum	20.9	0.0	9.7	15.9
Top of the skull	NA	2.7	9.9	NA
Vertebra 1	NA	NA	7.4	NA

quite high, which suggests that the body was moved but not significantly scattered. The other three maps exhibit much higher degree of dispersion, directional trend, and scattering: the body is being broken down in several parts that are widely scattered around the study area. The average for all dates can be used to compare the patterns for individual dates with the general distribution of all the body parts surveyed.

4. Discussion

4.1. Vulture scavenging and the postmortem interval

Several results in this initial pilot study are of immediate interest for estimating the postmortem interval. First, vulture scavenging can skeletonize a fully fleshed human body in less than 5 h. Because the process of complete skeletonization of fully-fleshed human remains is typically associated with longer postmortem interval rates, depending on the amount of time it takes for vultures to initiate feeding on fully-fleshed human bodies, times since death estimates at vulture scavenged scenes can be potentially misleading (i.e., 2 days versus 6 months). Canid scavengers have been shown to display patterns of dispersal of human skeletons [5] and previous research on vulture scavenging of pig carcasses also confirmed dispersal, although it was confined to a small fenced in area [1]. Thus, it was previously unknown whether vultures could disperse skeletal elements, and if so, at what distance. As a result of these findings, it is clear that the potential exists for the introduction of serious errors in estimating the time since death interval of vulture-modified human remains. This research represents the first controlled study of vulture scavenging of human remains at FARF. In this initial pilot project, it took vultures 37 days to initiate active scavenging of human remains. This contrasts with the previous study by Reeves [16] at FARF conducted during July through September, where it was shown that vultures only waited 24 h to begin actively scavenging pig remains.

This study represents the first attempt to examine vulture scavenging of human remains, and the initial findings of this multi-year project examining the degree and patterning of vulture damage, the effects of vulture scavenging to the human decomposition sequence, and the spread and distance of disarticulation underscore the need for further research in order to address consequences to time since death estimations and to develop strategies for locating missing skeletal elements. The on-going research project will continue to identify these vulture scavenging trends, to define taphonomic indicators left on the body and at the death scene, and to develop accurate techniques to estimate the postmortem interval in the presence of vulture scavenging.

4.2. Positional accuracy and the role of GIScience

As a result of this first pilot use of GIS and GPS mapping methods to track spatial patterns of vulture scavenging, two points must be underscored. The first concerns the accuracy of the GPS survey conducted. Table 2 shows the average positional accuracy, in the horizontal and vertical dimensions of the measurements taken at a certain date. The accuracy is especially high on January 10, 2010 and March 7, 2010, with an average of 6.6 cm (2.6 in.) for all measurements; the lowest accuracy value of 8.6 cm (3.41 in.) was attained for the survey conducted on November 23, 2009. Overall, the accuracy values are adequate, considering the size of the study area, and we are confident that the patterns discussed in the preceding section do reflect the situation on the field. Also in Table 2, note that the vertical accuracy of the measurements taken is considerably lower than the horizontal accuracy; this is a well-known limitation of GPS technology and is expected. Finally, the PDOP (Position Dilution of Precision) is a function of the geometry of the satellites at the time of the survey and correlates with the accuracy of the measurements: the lower the PDOP value, the higher the expected accuracy.

Table 2
Summary positional accuracy values (in inches) of the GPS survey.

Dates	Average positional accuracy		Average of PDOP
	Horizontal	Vertical	
23 November 2009	3.41	4.88	2.40
10 January 2010	1.80	3.17	1.79
18 January 2010	2.91	4.87	2.41
7 March 2010	2.04	3.20	2.04
10 June 2010	3.13	5.76	4.80
Average for all dates	2.63	4.44	2.89

The second point concerns the potential for GIS, GPS, and remote sensing technologies, coupled with the analytical methods of GIScience, to be fruitfully employed in the study of scavenging. We are still in the initial stages of utilizing these tools and methodologies, and more research needs to be done to understand which spatial patterns are of the most value and which are of less importance. For example, 3D modeling might shed light on the interrelationship between scavenging patterns and terrain by allowing the researcher to study the relation between scavenging and disarticulation patterns and slope, aspect, and a variety of other spatial analytical measures.

5. Conclusions

Based on the daily observations at FARF during this pilot study, vultures waited 37 days before the initiation of active scavenging and once begun, took ~5 h to render the completely fleshed individual to a skeleton. Previous research focusing on postmortem interval (PMI) estimates of scavenged remains involved the use of cross-sectional forensic anthropological case studies without knowledge of the interim sequences and processes that occurred from the point of deposition to discovery. Based on this pilot study, scavengers such as vultures have been shown to significantly alter the PMI, and thus PMI estimates derived from cross-sectional data rather than longitudinal research can be misleading. Furthermore, the use of GIScience methods and technologies in documenting the patterning and dispersal of scavenged remains has the potential of providing spatially based insights which can lead to predictive modeling applications for the recovery of skeletal elements from scavenged scenes.

Our long-term objective for this project is to develop standardized mapping and identification procedures that can be applied in a variety of situations, environmental conditions, terrain characteristics, and different scavenger species beyond vultures. This paper highlights the first attempt at developing such a quantitative methodology, and contributes to an understanding of the interaction between vultures and human bodies in order to assist forensic investigators in achieving more complete death scene recoveries and in providing more accurate postmortem interval estimations at vulture modified scenes.

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