AN INVESTIGATION OF THE TAPHONOMIC EFFECTS OF ANIMALS SCAVENGING

by

Alexander Garcia-Putnam

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Director of Thesis/Dissertation: Dr. Megan Perry

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Numerous environmental and human-induced variables that affect decomposition can cloud accurate estimations of the postmortem interval (PMI). For instance, scavenging animals can remove soft tissue and disarticulate and scatter remains, resulting in faster-than-expected decomposition. This study investigates the impacts of animal scavenging on decomposition rates and estimations of the PMI in eastern North Carolina using pigs (*Sus scrofa*) (n=4) as analogs for human remains. Systematic observation over a five-month period documented which scavengers affected the deceased human bodies, the decompositional changes of each subject, and the scattering patterns of the skeletal elements to determine whether or not scatter patterns over time can be predictive of the postmortem interval. One specimen enclosed in a wire cage served as a control. Motion sensing cameras were positioned at the three exposed sites to capture images of scavenging animals. Vultures and canid scavengers produced the most pronounced scattering events. The exposed remains reached full skeletonization and disarticulation by day 8, while the control reached a skeletal state by day 16. This research finds that there are general trends in both scavenger activity over time and scatter of the remains over time, therefore a relationship was found between scatter area and PMI. Studies of this nature are critical in aiding in the estimation of the PMI in real-world medico-legal investigations in eastern North Carolina.

# AN INVESTIGATION OF THE TAPHONOMIC EFFECTS OF ANIMAL SCAVENGING

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Alexander Garcia-Putnam

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Alexander Garcia-Putnam

APPROVED BY:

DIRECTOR OF
DISSERTATION/THESIS: ______________________________

Megan Perry, PhD

COMMITTEE MEMBER: ______________________________

Charles Ewen, PhD

COMMITTEE MEMBER: ______________________________

Edmond Boudreaux, PhD

COMMITTEE MEMBER: ______________________________

Lisa Leone, MA

CHAIR OF THE DEPARTMENT
OF ANTHROPOLOGY: ______________________________

Randolph Daniel, PhD

DEAN OF THE
GRADUATE SCHOOL: ______________________________

Paul J. Gemperline, PhD

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# CHAPTER 1

# INTRODUCTION

A critical component to medico-legal death investigations is the estimation of the post mortem interval (PMI), or the amount of time that has passed since the death of an individual until discovery. An accurate PMI allows investigators to corroborate witness statements, test alibis, and more fully understand the perimortem and postmortem timeline leading up to the discovery of a corpse (Mann et al. 1990: 103). To that end, the paleontological concept of taphonomy has been adopted and relabeled for medico-legal purposes as 'forensic taphonomy' to describe the processes that act upon human remains after death until discovery. Taphonomic contributors include things like temperature and precipitation, as well as burial conditions, trauma on the remains, and scavenging animals. It is this final taphonomic influence that is the focus of this study. The purpose of this experiment was to shed light on how scavenging animals affect corpses and, in particular, if there is a correlation between distance of spread of scavenged remains across the landscape and PMI.

Patterns in human decomposition need to be investigated on a local scale, as minute changes in environment can alter the processes that act upon human remains after death. Postmortem alterations by scavenging animals can cloud accurate PMI estimation, as they impact the rate and sequence of body decomposition. Other environmental and climatological factors can influence decomposition rates as well, and need to be taken into consideration when constructing localized PMI models. I will first outline the techniques traditionally used to estimate PMI to study how scavengers impact the decomposition process and the importance of constructing localized micro-environmental decomposition sequences that take scavenging into consideration.  These data then will be used, if possible, to generate a model for using scavenging sequence and pattern as a predictor of PMI.

In order to understand the relationship between animal scavenging, decomposition, and PMI estimation, this project used pigs as substitutes for human remains and subjected them to environmental conditions similar to bodies found in eastern North Carolina. I studied how scavengers like vultures and coyotes disarticulate and scatter the bodies, and if this scatter pattern and associated passage of time could be used to estimate PMI.  Using a laser transit mapping tool called a total station and motion sensing cameras, I was able to ensure that I could track which scavengers affected the deposition site, and how they influenced the scene by locating and mapping which body parts were taken, and how far they spread over time.  Using various spatial modeling tools on the program ArcGIS, maps of the scatter distribution were created to visualize this spread, and changes in spread area were noted over time.  The photographic evidence from the motion sensing cameras gave a glimpse of which animals are responsible for the scattering of carrion in eastern North Carolina, and in what order they visit the corpse.

# CHAPTER 2

# BACKGROUND

In this chapter, previous research into human decomposition and forensic taphonomy will be highlighted to shed light on the theories and methods researchers use to estimate the post mortem interval (PMI) and what variables can influence researchers' estimations of the PMI. In particular, previous work regarding scavenging animals' roles in that process will be introduced. It is necessary however to start more generally, to look at the decomposition process and work being done studying the morphological changes associated with time since death.

William Bass and colleagues at the University of Tennessee Knoxville's Anthropological Research Facility (ARF) pioneered much of the research on human decomposition (http://web.utk.edu/~fac/). The facility, often referred to as 'The Body Farm,' allows research of the postmortem processes that affect human remains in natural and manmade settings. Bodies are deposited in the facility as soon after death as possible from multiple of body donation services. Once at the ARF a cadaver can be used for any number of research projects, investigating a multitude of body habitus, including clothed, un-clothed, buried, on the surface, or wrapped in plastic. Prior to the formation of the ARF, there had never been systematic research on the decomposition of human remains. Initial research at the ARF proved that the numerous variables that influence decomposition could be studied experimentally, even if many of these variables were interrelated and could not be controlled for individually (Mann et al. 1990: 104). Since the creation of the ARF, numerous other facilities have sprung up around the United States. Texas State University's Forensic Anthropology Center is a newer outdoor laboratory and observation facility that serves as an arid contrast to the climate of eastern

Tennessee (http://www.txstate.edu/anthropology/facts/). Facilities in Western North Carolina (ww.wcu.edu/academics/departments-schools-colleges/cas/casdepts/anthsoc/academic-programs/foranth/), and Southern Illinois (http://cola.siu.edu/anthro/cfar/) also do similar research. This is encouraging, as more facilities available in various regions and climates will lead to the creation of more localized decomposition sequences. Experimental studies done at these laboratories can be combined with data gathered from crime scenes to continue to fine tune death investigations, especially in regard to decomposition rates.

In medico-legal circumstances concerning skeletonized, burned, or dismembered remains, it is the job of forensic anthropologists as well as forensic pathologists to interpret the deposition site to determine PMI, among other aspects of the case. In a research context, it is often easier to use animal rather than human models to investigate these circumstances. The acquisition and use of human remains for anthropological research is often fraught with difficulties. Some think it unethical, cruel and downright disturbing. There are numerous legal barriers, and the process of acquiring human remains can prove to be arduous. As a result, researchers have long used animal remains as stand-ins for human remains (Payne 1965: 593; Morton and Lord 2006: 475; Reeves 2009: 523; Dabbs and Martin 2013: 21; O'Brien et al. 2007). Dogs, cats, and pigs have all been used as models. Dogs, though roughly similar in size to humans, have such thick coats of fur that decomposition processes are drastically different, and therefore they are not reliable models for human decomposition studies (Payne 1965: 593). Pigs, however, present the strongest case for use as models for human decomposition. They are roughly equal in weight, and they also have similar amounts and distributions of body hair. Most notably their anatomy (muscles, bones, and organs) are markedly similar to human beings. Through previous research it has been shown that pig decomposition parallels human decomposition, making pigs the obvious model of choice for this research project (Payne 1965: 593; Morton and Lord 2006: 475; Reeves 2009: 523; Dabbs and Martin 2013: 21; O'Brien et al. 2007).

*Stages of Decomposition*

In order to categorize and conceptualize the complexities of the decomposition process, researchers have created a number of stages that illustrate the defining changes occurring during decomposition. In reality it is a continuous process, not a series of defined stages (Carter 2007: 14; Payne 1965: 594-595; Megyesi et al. 2005: 1). Nonetheless, employing a five-stage approach is useful in creating postmortem timelines. Each stage, 1) *fresh*; 2) *bloat*; 3) *active decay*; 4) *advanced decay*; and 5) *dry/skeletal*, corresponds to an amount of time since death, factoring in local environmental considerations (Payne 1965).

The *fresh* stage begins immediately after death, when aerobic activity totally ceases (Payne 1965: 596; Carter et al. 2007: 12). Key markers of *fresh* remains are *algor mortis*, *livor mortis*, and *rigor mortis*, whose onsets can further segment the beginnings of decomposition (Sledzik 1998; Dawson and Rhine 1998). *Algor mortis* describes the cooling of a body's core temperature after death that occurs at a relatively known rate. The internal temperature falls to meet the temperature of the surrounding environment, and is therefore highly correlated to seasonal and micro-environmental changes in temperature (Mathur and Agrawal 2011: 276). For this reason, temperature is taken rectally by investigators in order to minimize environmental influence (Mathur and Agrawal 2011: 276). This known rate allows pathologists to estimate PMI to roughly 24 hours after death (Tibbett 2008: 30; Mathur and Agrawal 2011: 276). *Livor mortis* occurs with the cessation of blood flow; as the blood in the body becomes stagnant, gravity causes it to pool in the lowest areas of the body (Tibbett 2008: 30). This pooling is visible on the skin as red or purple staining, and generally becomes fixed eight to eighteen hours after death (Tibbett 2008: 30-31; Rhine and Dawson 1998: 145). *Rigor mortis* is the process of muscular rigidity after death; its onset is at approximately 2-4 hours after death. After full rigidity sets in at approximately 12-18 hours it will slowly lessen until around 72 hours after death. In general the *fresh* stage is characterized by these three stages and initial colonization by blowflies and other insects. Initial blowfly activity can commence within minutes of death. The *fresh* stage ends when *bloating* begins.

The *bloat* stage is clearly visible by the swollen appearance of a cadaver. The lack of oxygen allows for anaerobic bacteria within the gut to flourish, producing gases that fill and inflate the corpse (Tibbett 2008: 31). There is also evidence of discoloration of the skin, called marbling and the first noticeable odor of death (Carter et al. 2007: 15). The internal pressure resulting from this gas build-up causes internal fluids to escape from the mouth, nose and anus (Carter et al. 2007: 15; Payne 1965: 596). Generally it is at this stage that maggot activity begins to rapidly increase due to the availability of putrefaction liquid; maggots can be seen protruding from the mouth, nose and other orifices. *Bloating* can begin roughly 48 hours after death and ends with the release of pressure either by rupturing or escape though natural orifices or entry points created by feeding maggots (Payne 1965: 596).

*Active decay* describes the process following the deflation of the remains (Galloway et al 1989: 608; Payne 1965: 597). Its end point however, is far more difficult to assess (Galloway et al 1989: 609; Payne 1965: 597). Remains in this stage of decomposition often present darkening discoloration of the skin due to liquefaction (Galloway et al. 1989: 608). There is voracious maggot activity as well as loss of internal fluids from the purge following bloating, resulting in what Carter et al. (2007) call “rapid mass loss”.

Following *active decay*, *advanced decay,* is characterized by a drying of the remains and further removal of mass as putrefaction fluids seep into the surrounding matrix.  At this stage some skeletal elements are visible and adipocere may develop (Galloway et al. 1989: 609). When more than half of the body's skeletal elements are exposed, the remains enter the final stage: *skeletal/dry* (Carter 2007: 16; Payne 1965: 597).  The *dry* or *skeletal* stage of decomposition is the true domain of the forensic anthropologist.  Forensic Anthropologists evaluate the bones in order to create a biological profile of the individual: stature, biological affinity, age, and sex. The goal of this work is to compile enough unique indicators to form a positive identification that will hold up in a court of law.  Skeletal remains will slowly break down overtime due to taphonomic processes like plant growth, scavenger activity, precipitation, and temperature fluctuations (Mann et al. 1990).  Bleaching over the months following death, if exposed to sunlight is also common (Mann et al. 1990). Skeletal elements will begin to degrade and break apart if left on the ground surface, a process called weathering; however, buried remains maintain their form for longer due to less environmental changes acting upon them.

*Estimating the Postmortem Interval*

Mann et al (1990) enumerate the key factors affecting deceased individuals; these include: temperature, humidity, trauma, burial, and scavenger activity.  It is crucial to understand local environment and climate to fully understand the taphonomic sequence that acts upon a corpse.

Temperature affects insect activity and thus decomposition rates more than any other variable. Mann et al. (1990) claim, "Under ideal conditions (warm to hot weather), it usually takes between two and four weeks for a body to become nearly to completely skeletonized."

Shean et al. (1993) explored the differences in decomposition between shaded and sunny deposition sites. They found that the sunny site's higher temperatures were enough to cause significantly more maggot activity, causing more rapid decomposition (Shean 1993: 948). Lisa Leone (2006), using Shean et al.'s (1993) model, conducted a decomposition study in eastern North Carolina, investigating the difference between shaded and sunny deposition sites. She found, similar to Shean et al. (1993) that the pig remains left at the sunny site decomposed at a significantly faster rate than the shaded remains (Leone 2006).

While temperature can bias our interpretations of PMI, it can be incredibly useful in helping to establish it. Using a system called accumulated degree-days (ADD), it is possible to accurately measure PMI to the day (Megyesi et al. 2005; Michaud and Moreau 2011). Megyesi et al. (2005) view "the decomposing body as a stopwatch whose hands are driven by temperature." Accumulated degree-days can be thought of simply as average air temperature since death. ADDs are a way to standardize time and temperature so that if, for example, you have 10 days with an average of 10 degrees Celsius, you have 100-degree days (10x10), but if you had an average of 2 degrees Celsius; you would need 50 days to get 100 accumulated degree days (50x2). So theoretically 100 ADD will show the same decomposition regardless of location or duration. Megyesi (2005) and Michaud and Moreau (2011) stress the use of quantitative analysis such as accumulated degree-days rather than the qualitative stages of decomposition as "it opens new doors for researchers and allows for the inclusion of statistics in a science that is primarily descriptive and in urgent need of validation methods in courtroom proceedings" (Michaud and Moreau 2011).

Humidity, often coupled with discussions of temperature, is another influential factor in determining PMI. Mann et al. (1990) note in particular that in arid environments remains can mummify, inhibiting insect activity due to the hardening of the skin, and drastically lengthen the decomposition process. Mummification can occur in both cold and dry climates and hot and dry climates (Mann et al. 1990). Conversely, high humidity environments, which foster the proliferation of carrion insects, can cause rapid deterioration of soft tissue (Mann et al. 1990). It has been shown that rainfall does not have a significant effect on decomposition rates (Leone 2006; Mann et al. 1990).

Trauma to the body can have a profound impact on the interpretation of surface deposition sites as well as the decomposition process. Perimortem trauma, like sharp force injury or gunshot wounds, creates openings in the flesh, that act as easy access points for insects (Mann et al. 1990). Not all traumas are caused by humans, as is the case in Wood's (2008) work on trauma associated with crocodile attacks. Wood (2008) discusses crocodile behavior and digestive processes of the multiple species of crocodile in Australia, both peri- and postmortem in nature. Researchers such as Moraitis and Spiliopoulou (2006) discuss the difference in breakages between green-stick or fresh bone fractures likely indicative or perimortem trauma and dry-bone fractures due to postmortem trauma that can be used by forensic anthropologists.

Insect activity, which is influenced by many of the climatological factors discussed above, is critical for the determination of the post mortem interval. This is especially true when discussing buried bodies. Underground burial constrains the vast majority of insect activity; therefore it drastically slows decomposition. Burial also prevents scavenger activity. Mann et al. (1990) indicate that burial depth is correlated to speed of decomposition, maintaining that the deeper the grave the longer the remains will take to decompose. Various burial treatments, such as embalming and wrapping in plastic also slow down decomposition by further preventing insect activity.

Thus, much of the research on factors impacting decomposition rates have focused on insect activity (Payne 1965), differences in position and perimortem treatment, such as trauma or dismemberment (Haglund and Sorg 2002), and environmental and climatological variables like temperature and rainfall (Shean et al. 1993). Another aspect, often neglected or controlled against in experimental studies on decomposition rates, is scavenger activity (Haglund et al. 1988: 985). Scavenger activity can drastically alter decomposition processes through the consumption and movement of remains (Haglund et al. 1988; Haglund et al. 1989; Dabbs and Martin 2013: 20).

*The Effects of Scavenging Animals on Decomposition*

Scavenging animals can greatly disturb surface deposition sites and make interpretation of the PMI and cause of death more difficult. Scavenging animals can damage bones in a number of ways, based not only on their dental characteristics but also their preferred period during decomposition to consume or disturb the remains. Carnivores, such as canids, generally leave four different marks on bone: punctures, pits, scoring, and furrows (Haglund et al. 1988). Pits occur when the bite lacks the power to go through, but still indents bone. Furrows are deeper scores, or channels in bone. Punctures occur when an animal's tooth breaks through bone and creates a small hole. Scoring occurs when teeth drag across bone surface. Although at first glance scavenger tooth and claw marks may seem to mimic perimortem damage like sharp force trauma, it has been shown by Haglund et al. (1988) that there are noticeable differences between the two. Sharp force trauma follows "a straight, rigid course" while scoring from animal teeth "follows bone contours." Bears are responsible for some of the most dramatic alterations to human remains (Carson et al. 2000). Carson et al. (2000) illustrate that canids and bears consume and scatter different components of the body. Bears are more likely to remove and consume the arms and chest area, whereas dogs and coyotes mostly leave the abdomen alone and opt for the head and neck (Carson et al. 2000: 525). Other carnivores, such as vultures tend to leave shallow scratches on bone (Reeves 2009: 527). Rodents also can leave their mark on bones. Rodents generally gnaw on the ends of long bones and other areas with easy access to soft cortical bone (Klippel et al. 2007: 769). Being able to distinguish scavenger alternations to skeletal elements is vitally important to accurate death investigations.

One area of interest to those researching scavenging as a taphonomic process is how it results in the scattering of remains across the landscape. Scavengers can disarticulate and scatter skeletal elements, altering the deposition site and making PMI and other necessary determinations more difficult (Haglund et al. 1989: 587). Some research has indicated that patterns of disarticulation and scattering can aid in PMI sequencing. These patterns may also lead to predictive models that allow researchers and investigators to locate remains that have been scavenged and scattered (Haglund 1989: 587; Spradley et al. 2012: 57). Haglund (1989) indicates that certain skeletal elements are often found in association with one another including the "head with the first and second cervical vertebrae, rib cage with some cervical and thoracic vertebrae, including the sternum; the scapulae and upper extremities; and the lumbar vertebrae, pelvis, and lower extremities, particularly the tibia and fibula."

Much of the research done by Haglund et al. (1989) looks at the effect of canid scavengers such as coyotes and dogs. Canids and other carnivorous scavengers often disarticulate and drag remains back to burrows or dens for consumption. Vultures are also major contributors to the scavenging of carrion. Reeves (2009) showed that in central Texas, vultures could fully skeletonize remains in as little as 96 hours. Vultures are responsible for some disarticulation and far less movement of the remains than canids (Kjorlien et al. 2009:104; Spradley et al. 2012: 58). Haglund (1997) conceived of a number of questions to ask in a case involving dispersed remains that can help investigators get a clearer picture of the surface deposition scenes:

1. Are the remains scattered?
2. From where was the body scattered?
3. What is the skeletal element composition of the scattered groupings of bone?
4. What were the most likely trajectories and dispersion?
5. Are there any special circumstances that might affect disassociation of teeth or their scatter?

Haglund (1997) also illustrates the importance of creating maps of scattered remains. He indicates that the creation of these maps and diagrams could prove to be predictive of the relationship between scattering and PMI. The crucial element to this mapping is determining the original deposition site. The area of darkest soil staining, or items such as a murder/suicide weapon, clothing or other personal effects, may indicate the original deposition site. Large scavengers such as canids as well as bears can move whole bodies, and smaller elements can be transported easily by canids, vultures, and even rodents (Haglund 1997; Haglund et al. 1989: Carson et al. 2000: 515). Haglund (1997) creates unique disarticulation and scattering charts, using directional arrows scaled to scatter distance, and globular shapes to indicate deposition sites, or resting sites, in between scavenging scattering. These charts allow spatial and temporal visualization of the scattering process (Haglund 1997). Haglund (1989) developed a system to score carnivore scavenging on human remains. A score of zero indicates “the removal of soft tissue with no disarticulation” (Haglund 1989: 589). A score of one represents remains with destruction of the axial skeleton and removal of the upper limbs. Two represents removal of the lower limbs. A score of three indicates, “nearly complete disarticulation” (Haglund 1989: 589). Four represents “total disarticulation and scattering, with only cranium and assorted skeletal elements or fragments recovered" (Haglund 1989: 589). This scavenger-modified decomposition model will be tested on the experimental remains of this study. Piecing together the scattering process can lead to the discovery of disparate skeletal elements and can aid in establishing a more accurate PMI estimate.

Early studies on scavenging activity such as Haglund and colleagues' did not have access to the sophisticated satellite imaging, mapping software, and GPS data available today. Using Geographic Information Systems (GIS), it becomes possible to more accurately map surface deposition sites and visualize scatter distribution patterns (Manhein et al. 2006). Manhein et al. (2006) discuss the role of GIS in helping investigators to "understand the dispersal of human remains across the landscape as well as locations chosen by perpetrators for deposition of bodies." Using GIS and statistical spatial analysis in a study of 36 cases, Manhein et al. (2006) found no statistically significant relationship between time since deposition and distance between skeletal elements and the original deposition site, but they indicate that further research could reveal a positive pattern. Kjorlien et al. (2009) conducted similar research with 12 pig carcasses in Alberta. Canada, to test spatial analytical techniques for quantifying the spread distance and direction of remains being scavenged. They found that four out of 12 specimens were disarticulated and scattered randomly, while eight showed non-random patterns such as movement based on game trails or removal to a den location (Kjorlien et al. 2009). Both Haglund (1997) and Kjorlien et al. (2009) place importance on the presence of game trails as avenues for scavenging animals and as critical search locations for scattered remains.

The studies highlighted above indicate a high degree of variability in the influence of scavenger activity on surface deposition sites. Kjorlien et al. (2009) found patterns in the scatter, especially as they relate to game trails. Manhein et al. (2006) however found no statistically significant pattern among their cases. This current study, relying heavily on spatial analysis, should prove to be an interesting addition to the literature. If indeed there is a pattern between scatter spread and PMI, the methodologies used in this research could lay the groundwork for studies to come and aid local law enforcement and medical examiners in fine-tuning their estimations of the PMI of local cases involving scavenged remains.

As well as comparing the results of this study to these previous research projects, data from 12 forensic cases from eastern North Carolina that showed signs of animal scavenging were included in this work as a key local comparison. It cannot be stressed enough how important local factors are in estimating PMI and by incorporating these cases into this study, it allows for a more fine tuned comparison.

*Expected Results*

Using pig carcasses as analogs for human remains, I propose to study how scavenger activity in eastern North Carolina affects: 1) the rate of decomposition, and 2) the scattering of remains across the landscape. Because of the prevalence of large carnivorous mammals, scavenging birds, and rodents in eastern North Carolina, I predict that decomposition of the exposed carcasses will occur at a highly accelerated rate compared with the control specimen and will not necessarily follow the established decomposition sequences (Reeves 2009; Haglund et al. 1989). It is also being postulated that because the same study area was used, and the remains used were approximately the same size, the control specimen will decompose at a similar rate to the specimens used in Leone (2006). Additionally, due to the results published in previous research who used similar spatial analytical techniques, I expect the scattering sequence to be positively correlated to PMI; that is, the more time that passes since death, the farther the remains will spread. This is due especially to the presence of canid scavengers such as coyotes in eastern North Carolina, which have produced predictable scatter patterns in previous research (Hill 1987; Haglund 1997; Kjorlien et al. 2009).

# CHAPTER 3

# METHODS AND MATERIALS

In this research I interpret how scavenging animal activity affects surface deposition sites using four pig (*Sus scrofa*) carcasses. A baseline decomposition timeline based on one specimen enclosed in a wire cage will be compared to the three pigs left exposed to scavenger activity to monitor how animal scavenging affects decomposition rates. In addition, it is possible that the sequence of scavenging activity itself could be a useful means for estimating PMI. Using motion-sensing cameras and GPS mapping I will observe which wildlife species interact with the remains, as well as the distribution pattern of the scattered remains across the landscape (Dabbs 2013; Haglund et al. 1988; Reeves 2009).

## *Location and Duration*

This research project was conducted at East Carolina University's West Research Campus (WRC). The facility's 600 acres of land are used for undergraduate and graduate research in a diverse array of fields, including a prior decomposition study (Leone 2006). Four sites were chosen that exemplify various microenvironments of eastern North Carolina (Figure 1.). Site 1 and the control site are located in an open field of knee-high grass with few interspersed scrubby trees. Site 1 is located at a slightly lower elevation than the control site and saw occasional flooding. The control site, located approximately 30 meters from site 1, was spared from flooding. Both sites are located more than 50 meters from the access road. Sites 2 and 3 are located approximately 0.25 miles away from site 1 and the control site. Site 2 is located in a clearing in a small copse of pine trees, approximately 10 meters north of the access road. Surrounding the clearing are mature pine trees, thick vegetation, and brambles. Site 3, located 15 meters south of the same access road is in a very low elevation area and was flooded for the majority of the summer months. This swampy microenvironment was flat and cleared of all but a few tall grasses and scattered small pine trees. The experiment started on 12 June 2013, and all observable scattering activity ended 1 November 2013. The remains were not collected.

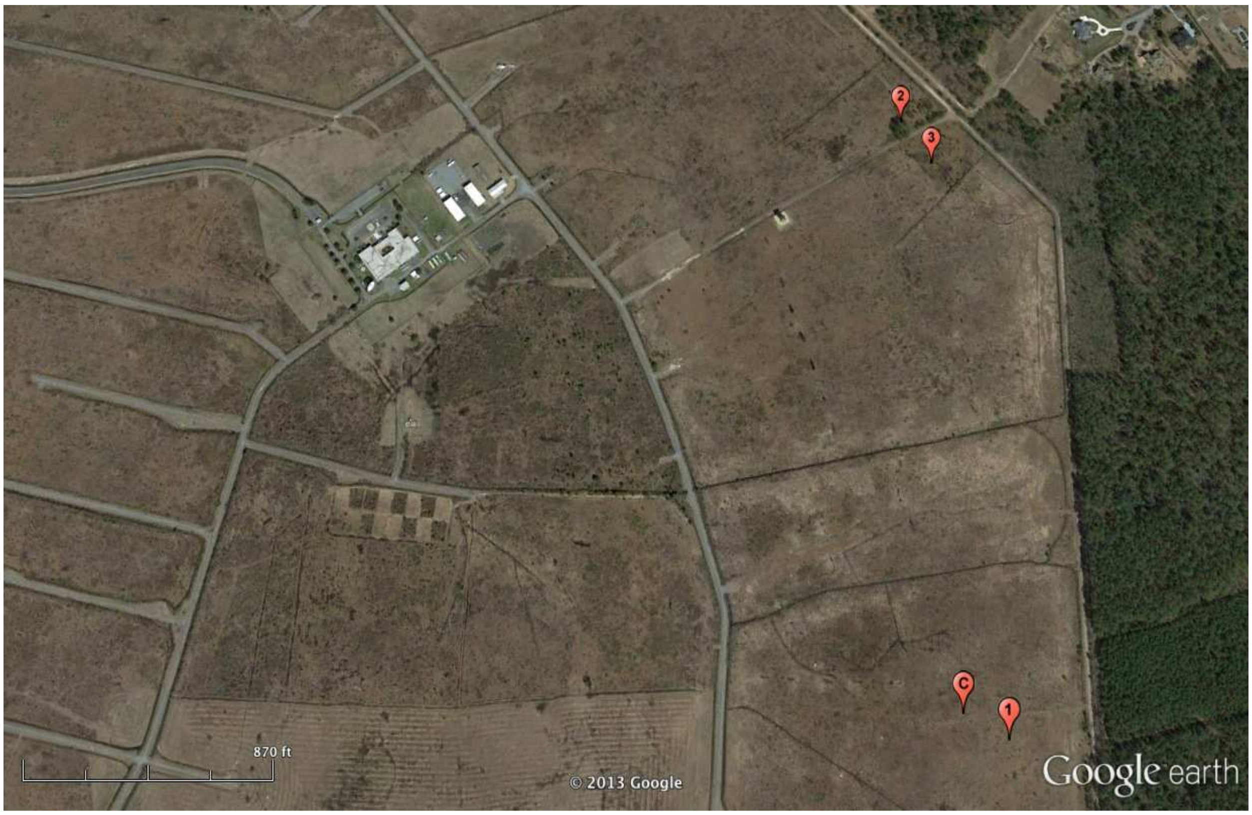

Figure 1. Satellite Imagery from Google Earth, labeled with sites 1, 2, 3, and the control (c).

*Materials*

Four pig carcasses (*Sus Scrofa*), acquired from Goldsboro Milling Company's Jordan Farm were obtained for this experiment. The experiment utilized pigs that were sick or injured and scheduled to be euthanized and not processed for consumption. Each pig weighed approximately 100 pounds. The pigs were euthanized by pneumatic bolt-gun by a Jordan Farm employee at approximately 10:00 am on 12 June 2013, and deposited at their respective sites at the WRC approximately two hours later.

To ensure that the control was not affected by scavengers, but still influenced by insects and the environment, I constructed a cage out of lightweight treated construction lumber and chicken wire. The cage was built large enough to ensure the pig would fit, and have ample room on all sides to make it difficult for scavengers to access the remains. The 1.0-inch mesh chicken wire was secured on all six sides of the cage by metal brackets and wood screws. The cage was 6’ long, 3’6” wide, and 3’6” high. One side of the cage was constructed as a separate piece so that it could be removed for observation and photographs.

Three Moultrie Game Spy A-5 motion-sensing game cameras were affixed to nearby trees or placed on stakes within view of the three exposed carcass. These cameras took still photographs once every ten seconds when activated by movement. They can also be set to capture short video clips, but for the purposes of this experiment, only photographs were collected. The cameras take color photographs during the day and also have infrared black and white capabilities for capturing images at night. A camera was not placed at the control site due to funding concerns and also in hopes that the cage would provide enough security and would not be penetrable by scavengers.

A digital thermometer and rain gauge were placed at the control site. The control site was chosen for the temperature and rain data collection site because it is open and exposed more than any other site. It is also the most centrally located of the sites. I collected temperature data every visit and took weekly precipitation readings.

On day 1 of the experiment, a Sokkia total station, a laser-transit mapping instrument, was used to establish the initial locations of the remains. A datum was established for the control site and site 1 on the access road. Another datum was set up on the access road between site 2 and 3.

*Experimental Design*

Day 1 of the experiment saw the retrieval of the pig specimens from Jordan Farms in Goldsboro, North Carolina. After the specimens were euthanized and loaded into the truck, they were immediately driven to the WRC to their final deposition sites. At the respective sites, the remains were laid on their sides, and oriented based on natural features and convenience for both access by the researcher and for clear unobstructed photographs by the motion-sensing cameras. The remains were also immediately photographed and their locations plotted by total station. From June 12 to June 23 the sites were visited daily, with each visit ranging from 45 minutes to 120 minutes. During short visits only photographs and field notes were collected. Visits when the remains were mapped using the total station were of longer duration, although efforts were made to keep visitation short and unobtrusive to not disturb scavenging animals for longer than necessary. Visitation reduced to every third day from June 25 to July 9 as decomposition activity lessened and scattering events slowed down in frequency. From July 12 to July 30 I visited the site once a week. After July 30, visits were conducted every two weeks.

Each visit consisted of digitally photographing each set of remains, focusing on disparate skeletal elements and overall site images, to attempt to accurately photograph the extent of the skeletal scatter. For the control site, the side of the cage was removed to aid in photographing the remains. High and low temperature data was collected during each site visit, while precipitation data was collected once weekly until visits slowed to two-week intervals.

Observations and general field notes describing the condition of the sites, the presence upon arrival of scavenging animals, and the current weather conditions were recorded by hand.

The remains were mapped on day 1 using 11 reference points around the carcass, creating a baseline outline. As the remains began to be dispersed from their original location, single skeletal elements were mapped-in individually to capture the extent of the site, while large scatter groups were mapped using single points or by creating four corners that delineate their groupings. Large skeletal elements such as the pelvis, mandible, and cranium or large areas of soft tissue were mapped individually. Articulated remains were mapped as linear groups with points at each joint area. Part of the mapping procedure was a grid search for scattered skeletal elements. For days 2-4, scatter was limited to within 5 feet of the original deposition sites, and therefore an organized search was not necessary. Day 4-25 saw such drastic disarticulation and scatter that more exhaustive search patterns were employed. Site 1, contained by tall grasses, only necessitated a 5x5m search area to find all scattered remains during days 2-14. Site 2's search area is contained by heavy underbrush to an oval-shaped area 5m long and as wide as 3m across. Site 3 had slow dispersal but eventually became the largest scatter distribution. Due to the swamp's lack of vegetation, locating the dispersed remains could be done easily for a larger area, and a 5x15m area was regularly searched with each visit.

Once all scattering events ended, the remains were left in the field to investigate long-term taphonomic effects of weather exposure on skeletal elements. Visits from October 15 to January 15 took place once a month, and notes and photographs were taken to assess the weathering of the remaining elements.

Using ArcGIS, a computer mapping software, it is possible to create scatter maps of the deposition sites. By plotting the points taken by the total station throughout the experiment it is possible to visualize the extent of scattering events. Taking a single day's readings, plotting them as a single-colored series of dots, it is possible to run the spatial analysis tool Minimum Bounding on ArcGIS which connects the outermost points to create a convex hull or total extent area of the data. This allowed for area measurements as well as mean center measurements to be taken to allow comparison in a single site over time, as well as between sites. Also a standard deviation directional ellipse model was used to create an ellipse the size orientation of a single standard deviation. These two tests show whether the data was clustering, for instance, around the deposition site, and be able to compare this clustering to the total extent of the disparate skeletal elements recovered.

# CHAPTER 4
# RESULTS

Data on a number of environmental variables that can influence scavenging activity and decomposition rates were gathered in this study. In this chapter I will first outline the climatological information gathered in this study. This summary includes information on the changing surface conditions at each site throughout the experiment. I will also discuss the various scavengers and their effects on the decomposition and scatter of the remains. Finally I will detail the pattern of disarticulation and decomposition of the exposed remains, and the morphological changes associated with specified decomposition stages of the control.

### *Temperature*

Temperatures at the WRC ranged from 96 to 55 degrees F for the highs, and 77 to 32 degrees F for lows over 154 days of the study (Figure 2), reflecting the temperature range typical for summer and early fall in Greenville, NC. Average recorded temperatures for Greenville, NC during these months from 1981 to 2010 ranged from 68 to 91 degrees F for highs, and from 44 to 70 degrees F for lows, according to the National Weather Service (NWS 2013). Figures 3 and 4 display the high and low averages compared with the observed highs and lows at WRC, respectively. The observed highs were on average 1.59 degrees F lower than NWS averages. The observed lows were on average 1.57 degrees F higher than the NWS averages.

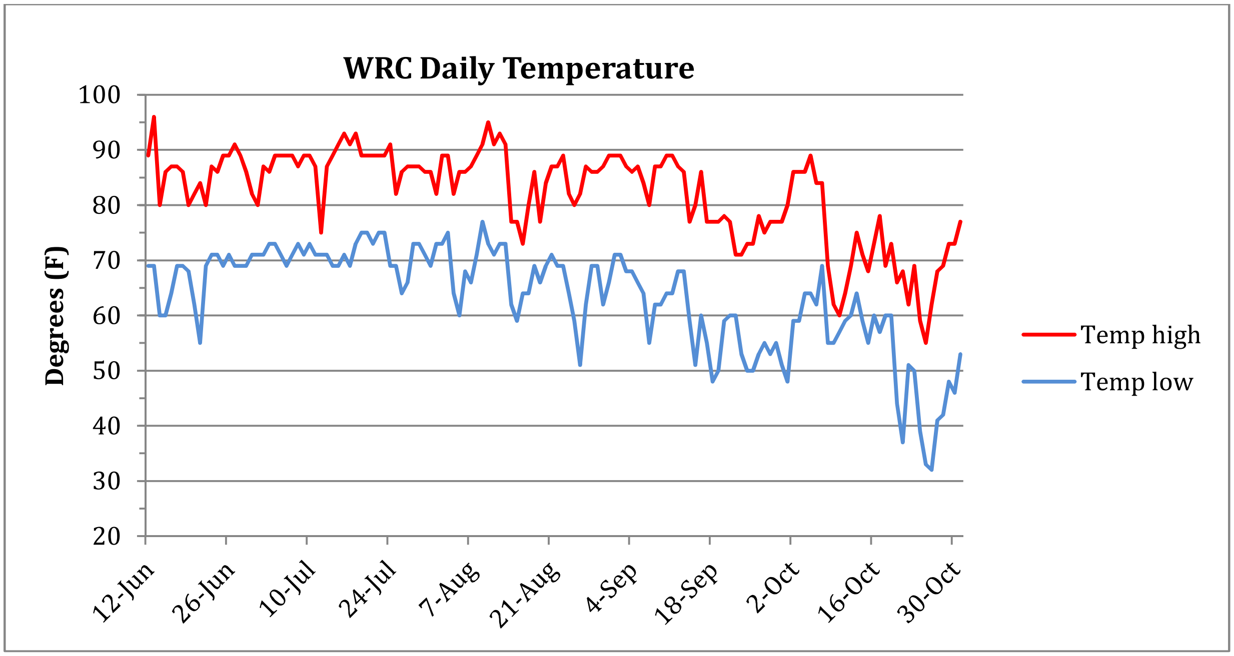

Figure 2. WRC daily temperature highs and lows recorded during the study period.

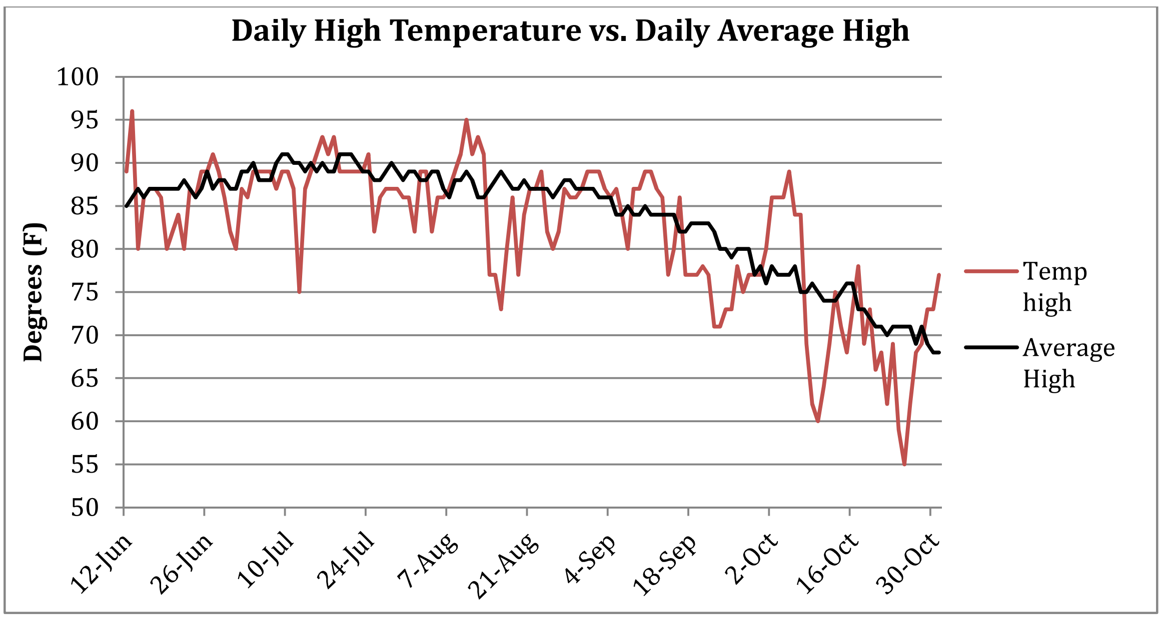

Figure 3. WRC daily high temperatures compared to daily average highs from 1981 to 2010.

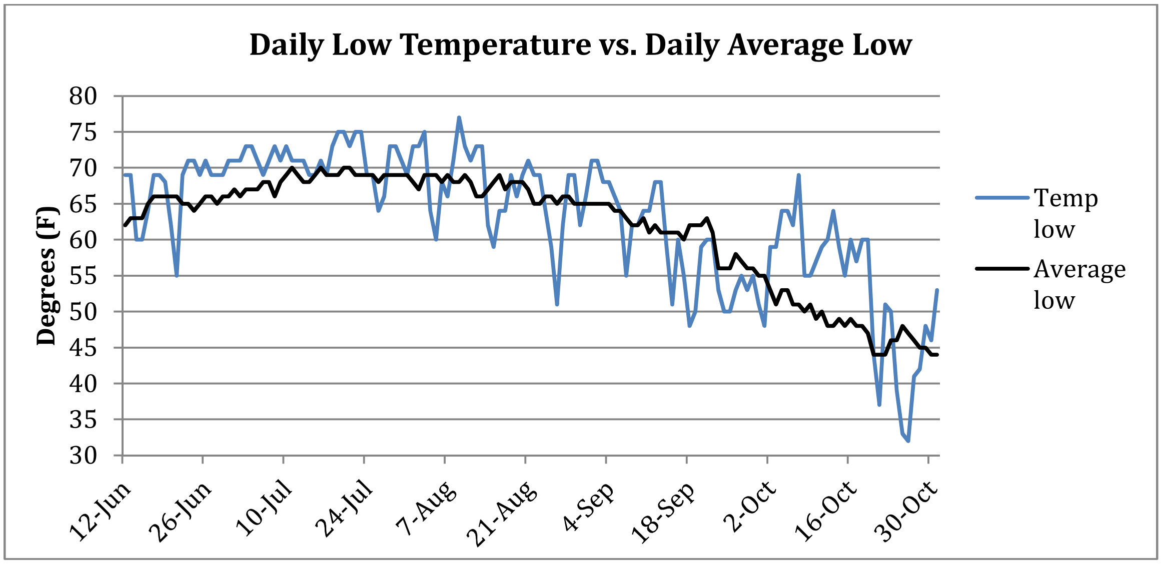

Figure 4. WRC daily low temperatures compared to daily average lows from 1981 to 2010.

*Rainfall*

Over the course of the study period, the rain gauge malfunctioned on multiple occasions, rendering the resulting data insufficient and incomplete. The rain gauge's base broke on one occasion, and the whole unit tilted over on two others. Data were acquired from a nearby weather station, approximately 3 miles east of the WRC, run by the NWS. Monthly precipitation amounts and the corresponding monthly averages are presented in Table 1. July had 1.35 inches above average rainfall, but August had 5.99 inches less than the average. Although these numbers would indicate a dry summer in general, the above average rainfall in July corresponds with a critical time in the decomposition process. For the complete weather data see appendices A and B.

Table 1. NWS observed monthly precipitation amounts compared to NWS averages calculated from 1981-2010.

| Month (2013) | Precipitation (inches) | Monthly Average Precipitation (1981-2010), (inches) |
|---|---|---|
| June | 4.15 | 4.31 |
| July | 6.74 | 5.39 |
| August | 0.15 | 6.14 |
| September | 5.5 | 5.83 |
| October | 2.2 | 3.25 |

*Site Disposition*

The control site, which was located on slightly higher ground than the adjacent Site 1, remained relatively static throughout the duration of the study. This site was chosen for the control specimen for its relative seclusion, moderate high ground, and ease of access. It was surrounded by small shrubs and high grass, but was exposed to direct sunlight and precipitation throughout the study. The cage itself was undamaged by scavengers and weather events throughout the study, and the control remains therefore can serve as a baseline to compare with the scavenged sites.

Site 1, located approximately 100 feet from the control site, was chosen because it was exposed to direct sunlight, and was accessible by the same trail as the control site. Located in an area of low grass, this site was surrounded by shrubs and high grasses and saw occasional flooding during the months of July and August. By day 75, August 25, the site was becoming overgrown with larger grass tuffs and weeds, making locating remains a challenge.

Site 2, located in a clearing in a copse of pine trees, remained very static and contained by thick vegetation surrounding the clearing. It was minimally affected by precipitation and sunlight. The pine trees shed their needles in early October, which spread evenly over the site, but had little effect on locating and identifying the remains. This site was specifically located here because of the tree cover, a rarity in the WRC, but a common microenvironment in eastern North Carolina.

Site 3, located in a swampy clearing, became flooded by day 8, and was under approximately 6 cm of water continuously until Day 75. Since day 75 occasional flooding occurred but for no sustained period of time. The conditions at Site 3 allowed for a unique chance to study the decompositional changes and animal habitats associated with the dynamic microenvironment of a swamp.

*Scavenger Activity*

A number of different scavenging animals visited the sites, including vultures, coyotes, raccoons, and domestic dogs. It is critical to understand what scavengers visited each site, in what order, and what damage, disarticulation, and scatter was done by each animal, in order to establish a clear understanding of how these animals influence corpses at surface deposition sites. Turkey vultures (*Cathartes aura*) visited each site within the first 24 hours. Site 1 had vulture activity by the middle of day 2 which persisted during daylight hours until day 13. Other than vultures, no other scavenging animals were observed at Site 1 during the study period. Site 2, on the other hand, saw multiple scavenging species visit the site. Vultures were present at Site 2 from day 2 through day 11, again only during daylight hours. A coyote *(Canis latrans)* was photographed scavenging a large section of soft tissue from the abdomen, as seen in Figure 5.

Site 3 had the first photographic evidence of vultures from the motion sensing cameras at 8:01am on day 2, 20 hours after the site was visited the day before. Vulture activity continued almost continuously during daylight hours until day 10 at Site 3. At Site 3 on day 6, the most vulture activity at one time occurred, with 11 vultures present at once, as shown in Figure 6. Site 3 was visited on day 6 by a coyote *(Canis latrans*) but it did not, according to the cameras on the site, scavenge the remains. At Site 3 on day 10, a domestic dog (a Weimaraner) was present, but was not photographed eating or disturbing the remains. However, on day 11, the motion sensing camera on Site 3 captured images of the same Weimaraner with another Weimaraner eating a rib and removing the cranium, as shown in Figure 7. The cranium was never recovered. The Weimaraners never visited Site 3 or any other site after day 11. Raccoons visited Site 2 and 3, on days 29 and 48 respectively, but there is no evidence to suggest that they scattered the remains. A summary of the scavenging activity can be seen in table 2.

Table 2. Scavenger visitation and effect on exposed sites.

| Site 1 | | | Site 2 | | | Site 3 | | |
|---|---|---|---|---|---|---|---|---|
| Animal | Duration (in days after death) | Elements scavenged | Animal | Duration (in days after death) | Elements scavenged | Animal | Duration (in days after death) | Elements scavenged |
| Turkey Vulture | 2-13 | Nonbiased scavenging of the remains, starting with ribs and vertebrae | Turkey Vulture | 2-11 | Nonbiased scavenging of the remains, starting with ribs and vertebrae | Turkey Vulture | 2-10 | Nonbiased scavenging of the remains, starting with ribs and vertebrae |
| | | | Coyote | 9 | Abdominal soft tissue | Coyote | 6 | No scavenging |
| | | | | | | Domestic Dogs | 10 | Scatter of ribs and removal of cranium. |


Figure 5. Site 2, day 9; Coyote scavenging remains over a 4-minute period. The red arrow indicates the location and movement of an area of soft tissue.


Figure 6. Site 3, day 6; turkey vultures scavenging the remains.

Figure 7. Site 3, day 11, Weimaraners removing cranium, indicated by red arrows; gnawing and scattering of a rib, shown in the mouth of one dog, circled in red.

*Decomposition and Disarticulation*

Decomposition was documented in the control specimen in order to provide a baseline against which to compare the scavenged remains to see the effects of scavenging on decomposition and skeletonization. Signs of progression through decomposition stages were recorded following Payne (1965). Insect activity was not recorded in this study. Although insect life stages are a decidedly accurate indicator of PMI, I chose to use visible morphological changes of the control specimen to segment its decomposition into stages.

**Control Site**

In the control specimen, the fresh stage, indicated by lividity, and the lack of bloating, lasted for the first 24 hours after death. At 24 hours, bloating began to appear and lasted until day 4 (Figure 8).

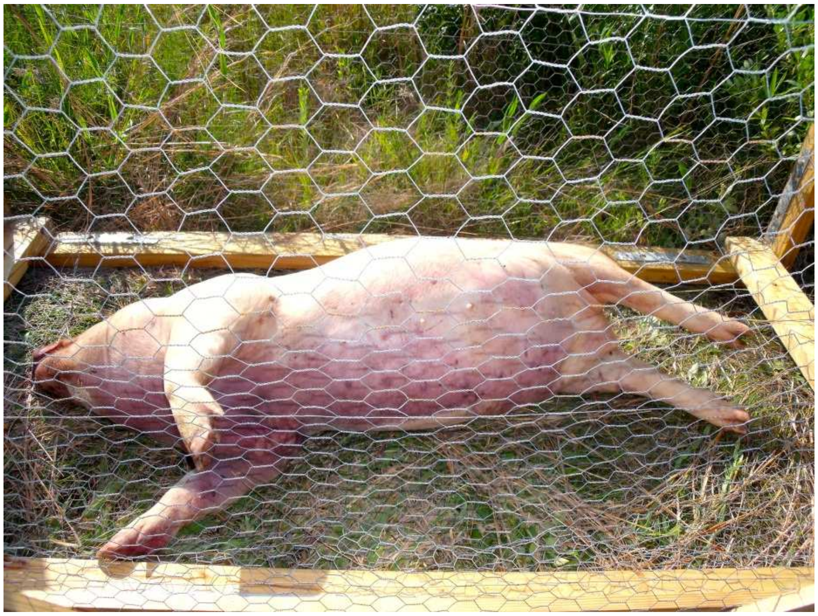
Figure 8. Livor Mortis and the bloat stage of the control specimen, day 2

Large maggot masses were present at the mouth and anus by day 3. By day 4 the bloat had begun to ease, not by a violent rupture, but instead a slow seeping of gasses from the maggot masses at the mouth and anus, indicating the start of active decay.  The active decay stage is characterized by a marked discoloration in the abdomen due to liquefaction and putrefaction of the internal organs, and the odor of decomposition was strong.  The surface maggot masses had decreased in size and activity from the previous day, presumably as a result of them burrowing deeper into the animal.  Over the next 4 days, maggots erupted through the skin of the abdomen and greatly accelerated the decomposition process.  By day 10, the control specimen progressed into advanced decay, which is characterized by a drying of the remains, and exposure of some skeletal elements (Figure 9). By day 15, the majority of the skeletal elements were exposed, and the remaining soft tissue had sloughed off and was seeping through the chicken wire under the remains.  By day 21 the skeletal remains began to bleach in the sun, and all insect activity was concentrated under the cage in the decomposition-fluid-saturated soil (Figure 10).  A summary of the decomposition stages and the morphological changes associated with them are presented in Table 3.

Figure 9. Advanced decay, control Site, day 9.

Figure 10. Skeletal stage, remains begin to get bleached by the sun, control Site, day 21.

Table 3. Summary of morphological and decompositional changes at control Site.

| Stage of Decomposition | Duration (In days since death) | Morphological Changes |
|---|---|---|
| Fresh | 0-1 | -Livor mortis<br>-Marbling of skin in abdomen<br>-Rigor Mortis |
| Bloat | 2-3 | -Expansion of the abdomen and stiffening of the legs to do tension from the expansion |
| Active Decay | 4-9 | -Bloat ends (with release of gases through maggot opening in face and anus)<br>-Marked darkening and discoloration of lower abdomen<br>-Skeletal collapse<br>-Exposure of internal organs |
| Advanced Decay | 10-15 | -Internal liquids seep out<br>-Drying of remains<br>-Some skeletal elements showing |
| Skeletal | 16-present | -More than 50% of skeletal elements visible<br>-Bleaching of bones over time |

**Site 1**

Site 1, located adjacent to the control Site, experienced voracious scavenger activity over the first 8 days of the study. On day 2 the remains had been partially defleshed and scavengers created a large opening in the abdomen, leaving the rib cage and internal organs intact, however (Figure 11). Day 3 saw an aggressive defleshing event, with limited disarticulation and scatter. The rib cage was collapsed, and the cranium was disarticulated from the vertebrae but remained close to its original position (Figure 12). The largest scattering event occurred on day 4. No internal organs remained, a large section of skin remained intact, the lower limbs and pelvis which remained articulated loosely were pulled 1 meter north, a section of articulated vertebrae was moved 1.5 meters south, and multiple ribs and disarticulated vertebra were scattered east of the deposition site (Figure 13). The scatter events on days 3 and 4 were the result of vulture scavenging, and although no photographic evidence is present for day 2 due to a camera malfunction, it can be inferred that the initial feeding was also by vultures.

Figure 11. Site 1, day 2. Initial scavenger activity but no scattering

Figure 12. Site 1, day 3; first scattered element, a rib, circled in red.


Figure 13. Site 1, day 4; original deposition site shown as blue rectangle, scattered elements circled in red.

At Site 1, Days 5-7 saw more gradual scattering of the remains, the skull began to bleach in the sun, and the large area of disassociated skin remained attached to the lower limbs but was being pulled north with the limbs.  By day 8, only the mass of skin and skeletal elements remained. The lower limbs were dragged further north, and were beginning to disarticulate.  Days 9-12 saw less voracious scavenging activity, and the subsequent scattering was less pronounced, although the area of skin continued to be picked over by vultures and moved 1.5 meters west on day 10. Days 13-28 saw all skeletal elements disarticulated aside from 5 vertebrae, and the remains began to bleach in the sun.  No scavenging activity that resulted in scattering occurred after day 28 (Figure 14).  As of day 49, grass began to grow in the clearing, and all skeletal elements remained stationary.

Figure 14. Site 1, days 28 and 49.

**Site 2**

Site 2 saw aggressive scavenging over the first seven days of the study. By day 2 the remains had the eyes removed, a portion of the rib cage exposed, and a tree branch that was previously above the remains had fallen onto the back legs (Figure 15). The motion sensing cameras captured images of the branch breaking under the weight of multiple vultures. There were minimal changes from day 2 to 3. Day 4 saw a massive scavenging event, where the remains were spun 180 degrees, the skull was disarticulated and scavenged clean, and the mandible was relocated 1 meter south of the deposition site. Meanwhile, the abdomen, and hind and forelegs were still held together by skin (Figure 16). On day 5 the fully articulated rib cage and vertebral column was relocated 1.5 meters west of the deposition site (Figure 17). Skin was pulled down over the articulated hind limbs and pelvis, and it was dragged 0.5 meters south of the deposition site.


Figure 15. Site 2, day 2 initial scavenger activity but no disarticulation


Figure 16. Site 2, day 4.

Figure 17. Site 2, day 5; Original deposition site is represented by the blue rectangle, the cranium, mandible and articulated vertebral column and rib cage are circled in red.

Days 6 and 7 saw little change from day 5. Some of the skin connecting the lower limbs was pulled south, but no noticeable scattering of skeletal elements occurred. Day 8 saw the disarticulation and scatter of an intact hoof, presumably preserved and protected by the skin folding down over it from the hind limbs. It was scattered 2 meters west of the deposition site. The skin mass was removed from the hind limbs and dragged 0.5 meters north of the deposition site. Days 9 and 10 saw movement of the articulated hind limbs 0.5 meters south, as a result of scavenging by a coyote (previously shown in Figure 5) and its removal of the large skin mass. On day 11, the articulated rib cage and the articulated lower limbs were moved north close to the original deposition site. The remains did not see any activity from day 13 to day 21. By day 25 the remains had disarticulated and began to bleach. This disarticulation was not due to scavenging, but by the natural decay process accelerated by heavy rains during this time. Days 25-115 saw no scattering events, only a slow bleaching of the skeletal elements.

**Site 3**

Site 3 saw rapid activity by scavengers: on day 2 the gut, anus, eyes, and nose were consumed by vultures (Figure 18). Massive maggot activity was present in the opening in the abdomen created by vulture scavenging on day 3, and the mandible began to be exposed. All of the internal organs were gone and the ribs were scattered south of the deposition site by day 4. Also on day 4 the cranium and mandible were disarticulated and moved 2 meters east and southeast respectively (Figure 19). Day 5 saw more rib and vertebrae scattering in all directions up to 3 meters away from the deposition site. The still-articulated hind legs were connected to a large skin mass and had been moved 0.5 meters east on day 6. On day 7 the articulated hind legs and pelvis as well as the skin mass was relocated 5 meters east of the deposition site in an area of tall grass, and the rest of the remains began to disarticulate and scatter as individual elements (Figure 20). Days 8-10 saw some initial flooding at the site, making locating the remains difficult.  On day 11, two domestic dogs removed the cranium from the site, and it was never recovered (Figure 7). During days 12-28 the site saw heavy flooding, little scavenger activity and no significant scattering events.  By day 49 the standing water was receding and the remains began bleaching in the sun, and no scavenger activity was observed thereafter.

Figure 18. Site 3, day 2; initial scavenger activity but no disarticulation

Figure 19. Site 3, day 4; original deposition site shown as a blue rectangle and scattered remains shown circled in red.

Figure 20. Site 3, day 7; original deposition site shown as a blue rectangle, scattered remains shown circled in red, and an arrow indicating the direction of travel of the articulated hind legs and skin mass, found 5 meters from the deposition site.

*Scatter Distribution Maps*

Using the program ArcGIS, I was able to produce maps of the scatter distribution and spread over the study period. By inputting the total station data into ArcGIS and performing a minimum bounded model called a convex hull for each data set, I was able to create polygons of each scatter area for each mapping day. Presented below are the maps for days 5, 17, 49, and 136 for Sites 1, 2, and 3 (Figures 21-34). The original deposition site is displayed on each map as a white polygon outlined in black. For each mapping day, all previous days' scatter extents are displayed as overlapping polygons, while that day's scatter is displayed as point features. On day 17, the data for Site 1 could not be recorded due to a malfunction with the total station. Despite this, general trends can still be gleaned from the data. On an unknown day between days 17 and 49, mowers who maintain the access roads at the WRC mowed over and obscured the datum and back-sight for the total station. Although we relocated the datum, the mowers removed the back-sight. Reestablishing the back-sight meant that the points were slightly shifted and did not match the pattern from the previous mapping day. We resolved this shift in the data by referring to images of the remains in the motion sensing cameras, which indicated that even though the data points had shifted, the actual remains were in the same place. Also using the cameras, I was able to establish three unmoved skeletal elements between the two mapping days. Using the ArcGIS editor function, I was able to shift the skewed data points back to an approximation of their correct position, using these three points as anchors.

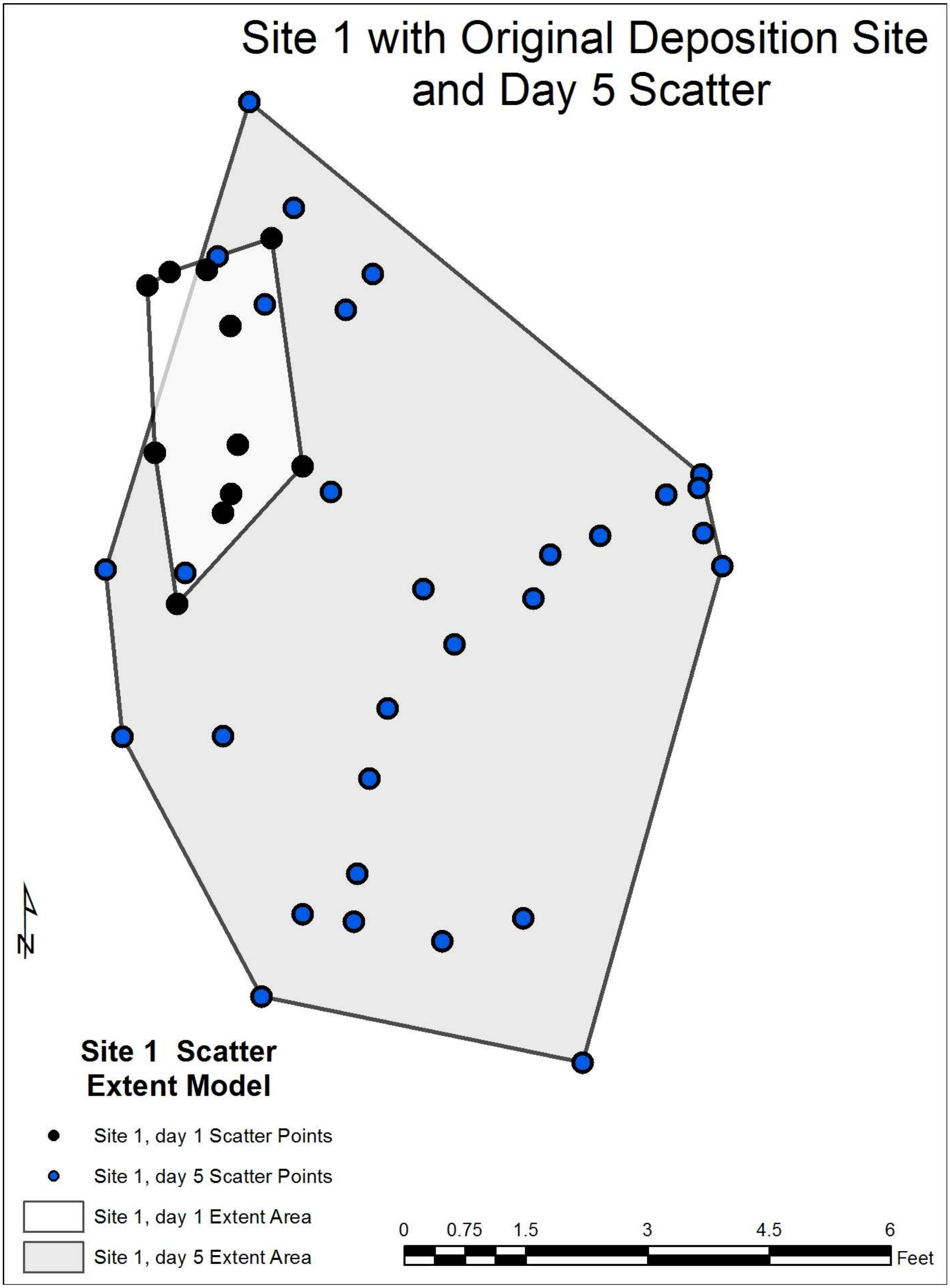


Figure 21. Site 1, day 5: scatter extent map.

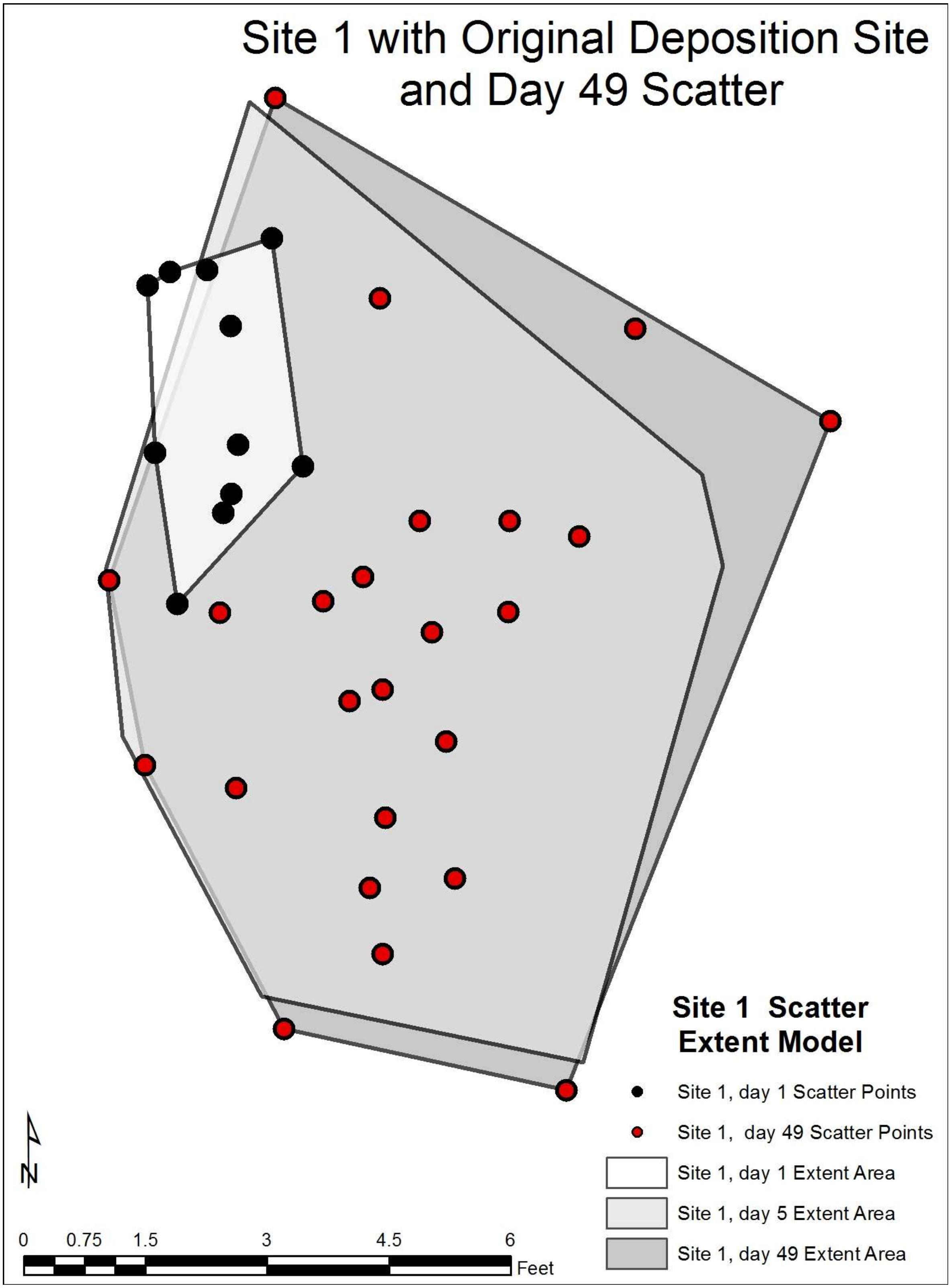


Figure 22. Site 1, day 49: scatter extent map.

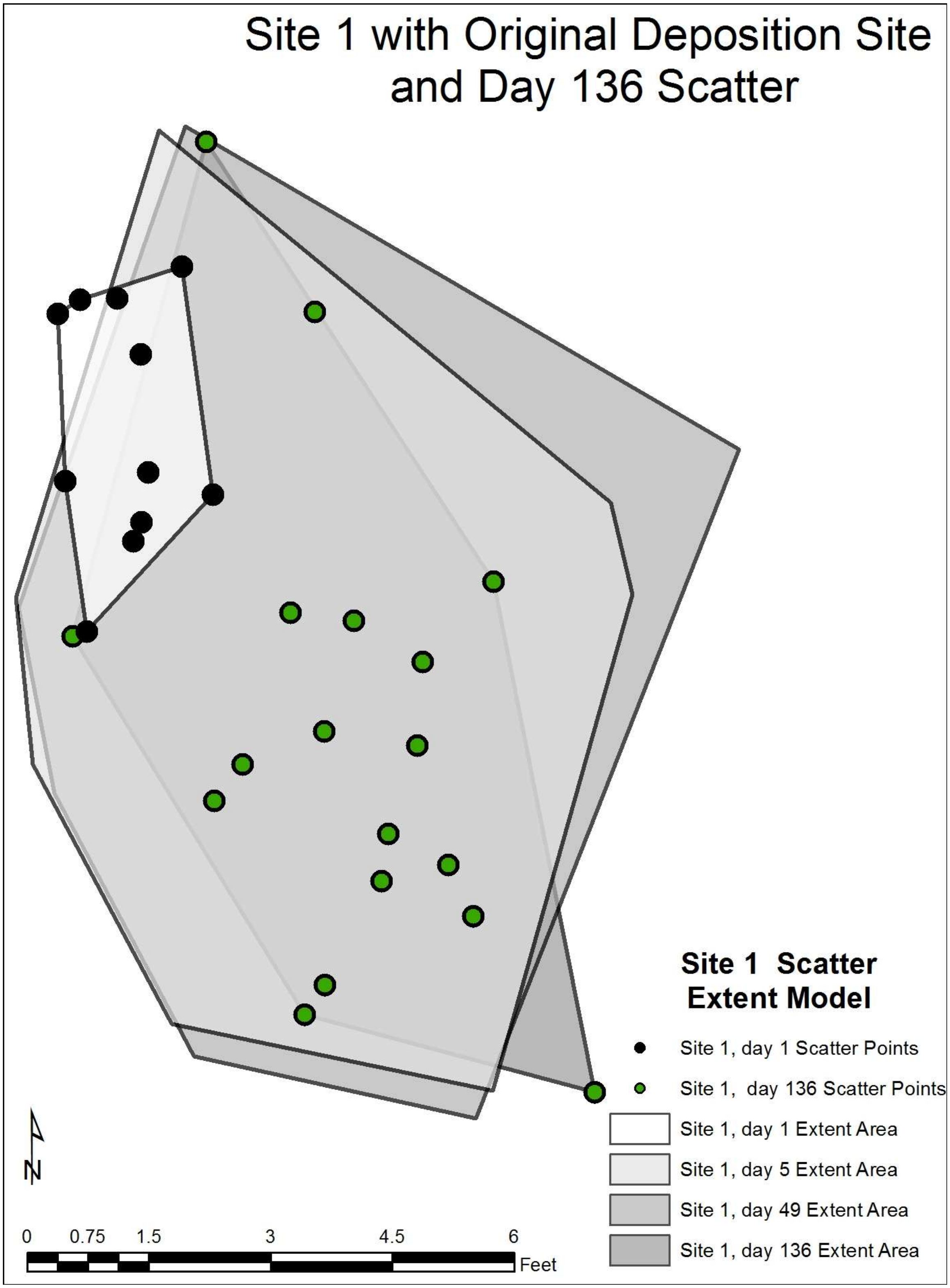


Figure 23. Site 1, day 136: scatter extent map.

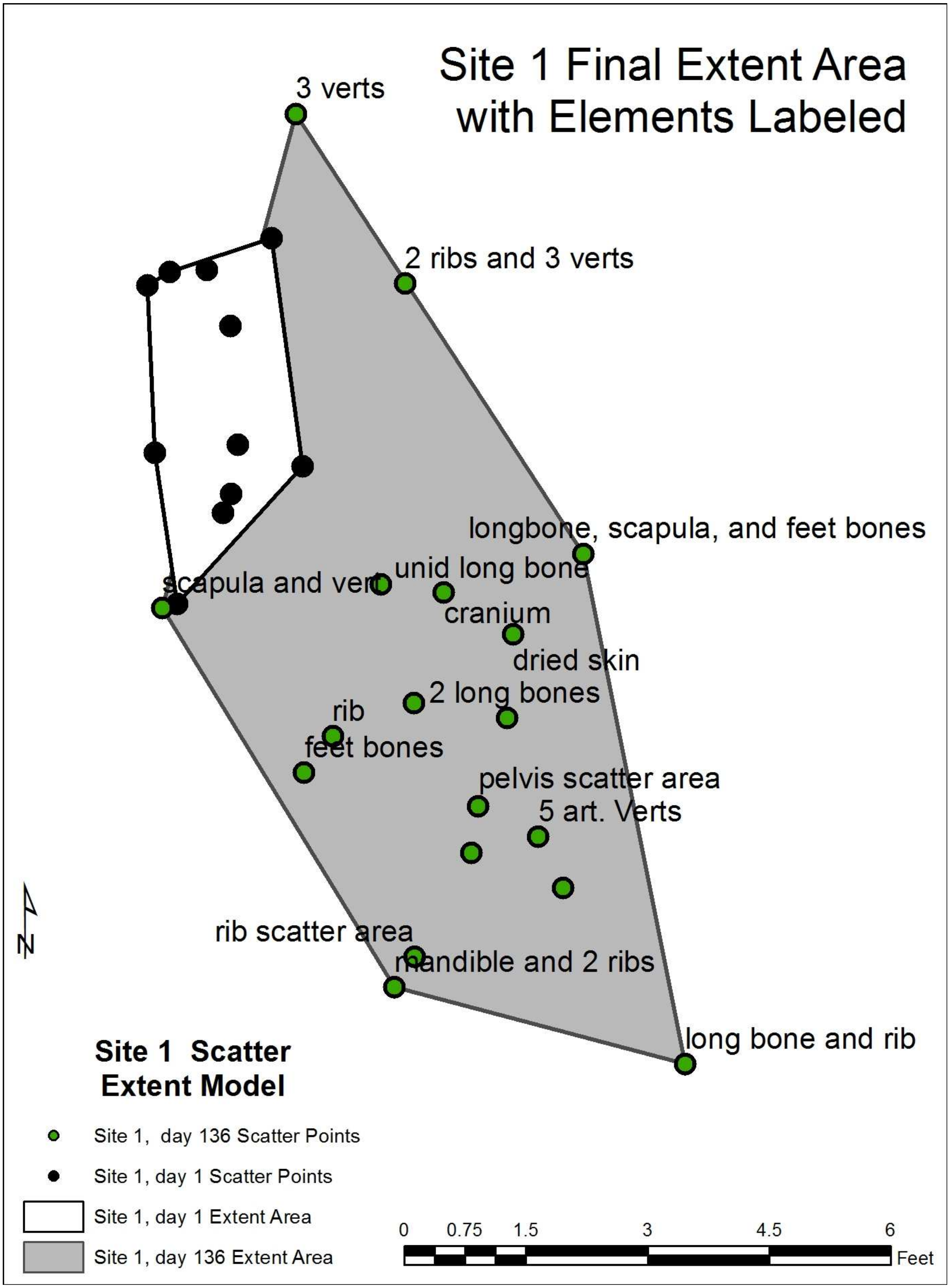


Figure 24. Site 1, final extent with elements labeled.

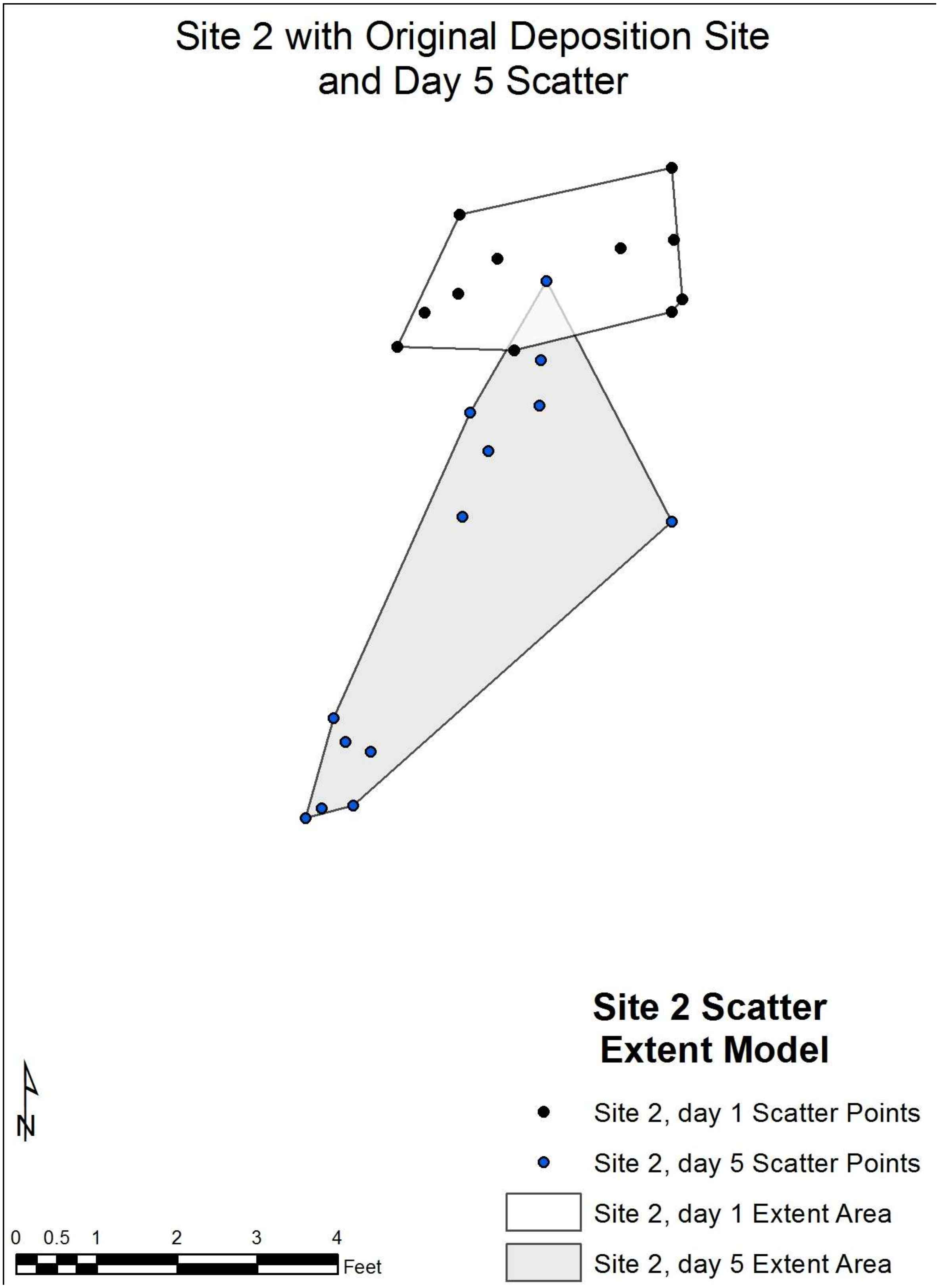

Figure 25. Site 2, day 5: scatter extent map.

Figure 26. Site 2, day 17: scatter extent map.

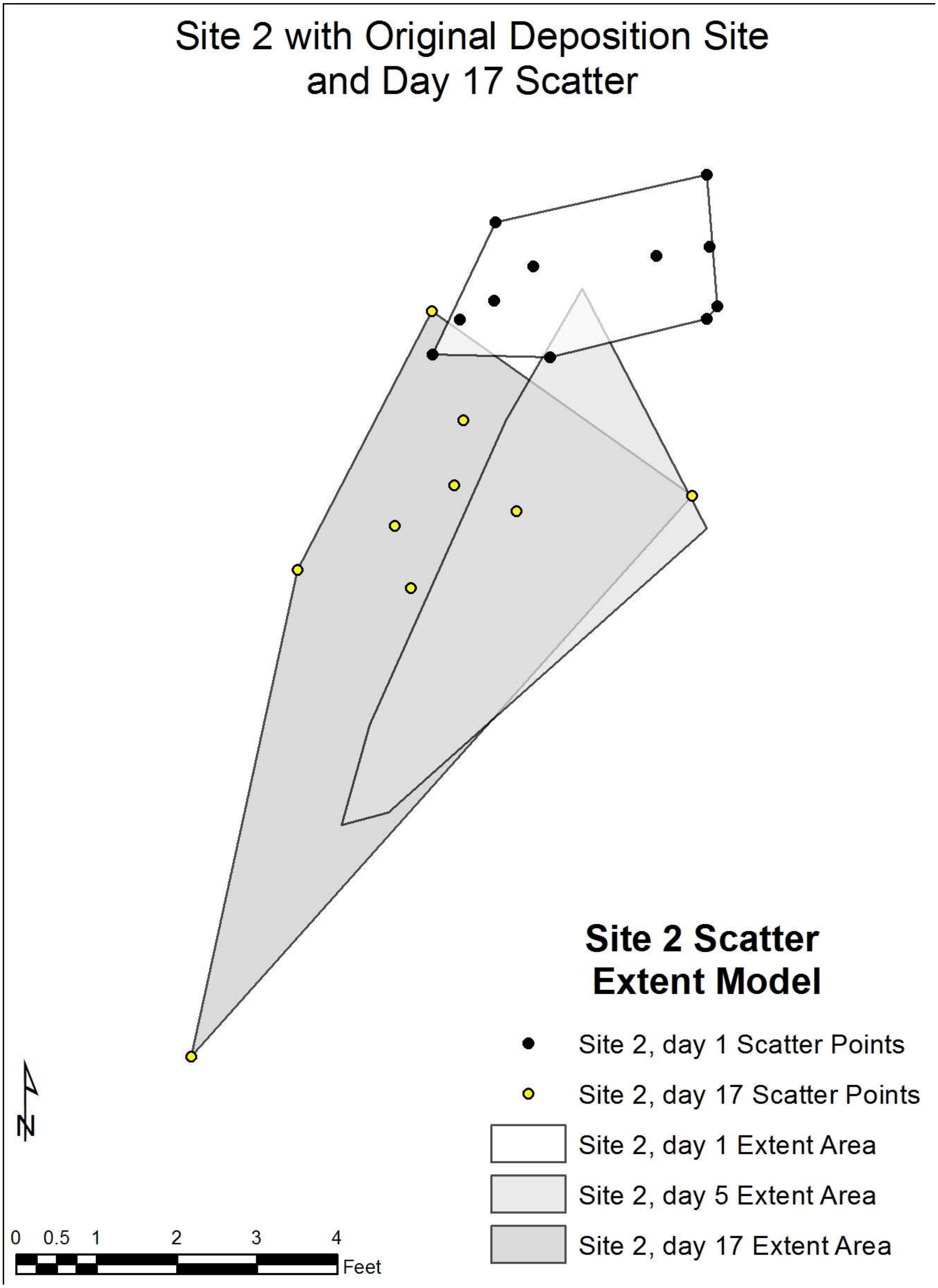


Figure 26. Site 2, day 17: scatter extent map.

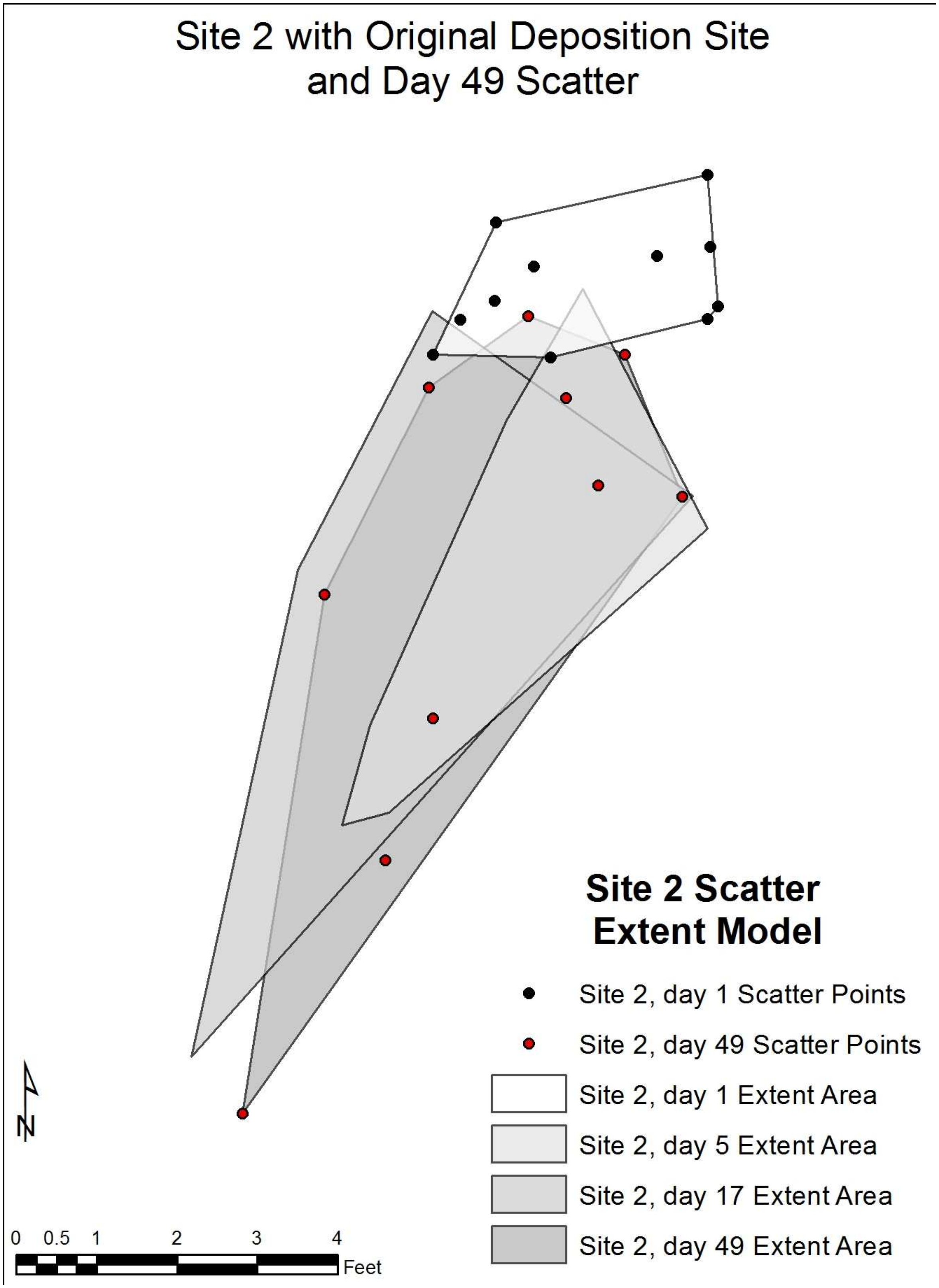


Figure 27. Site 2, day 49: scatter extent map.

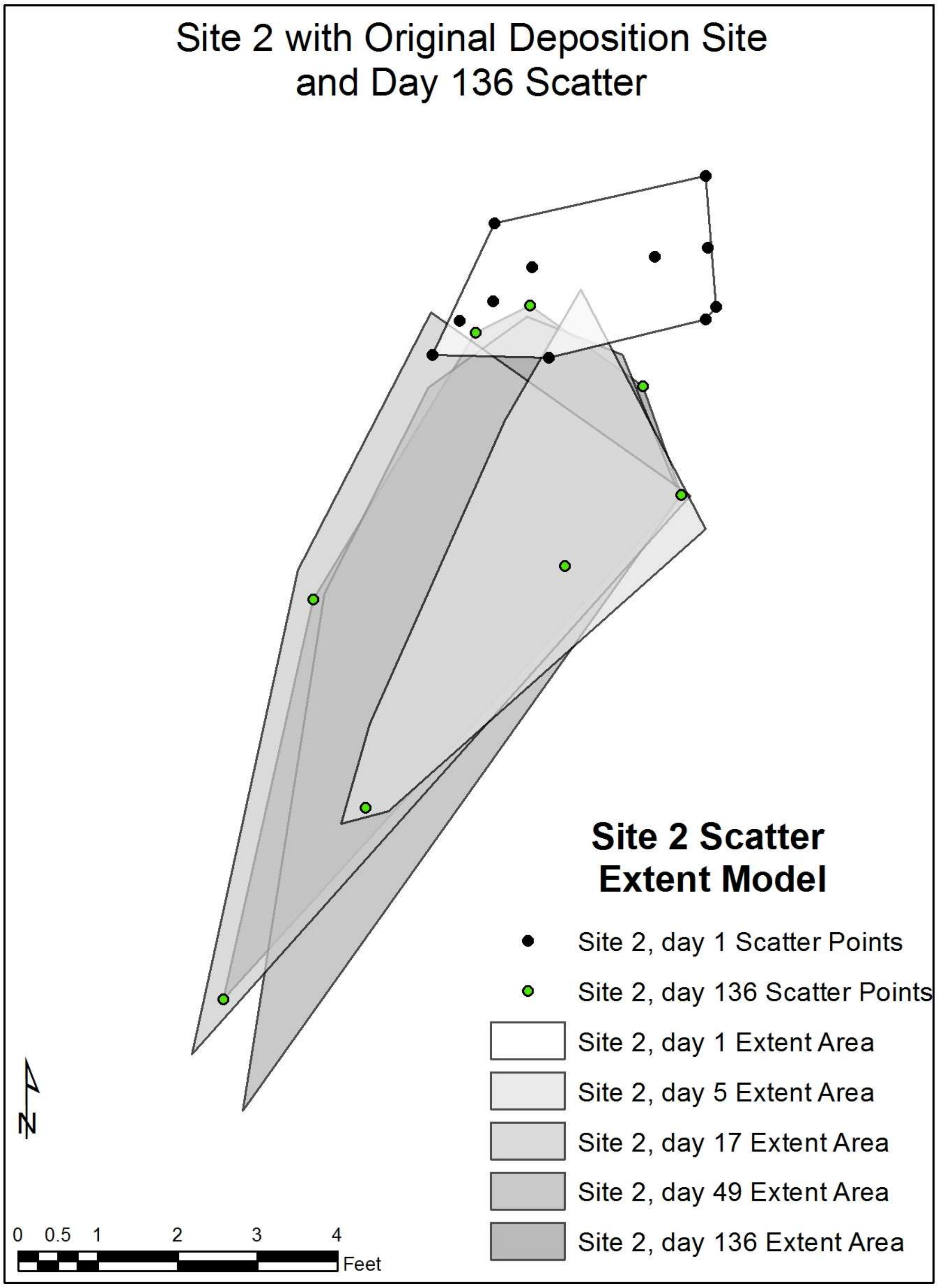


Figure 28. Site 2, day 136: scatter extent map.

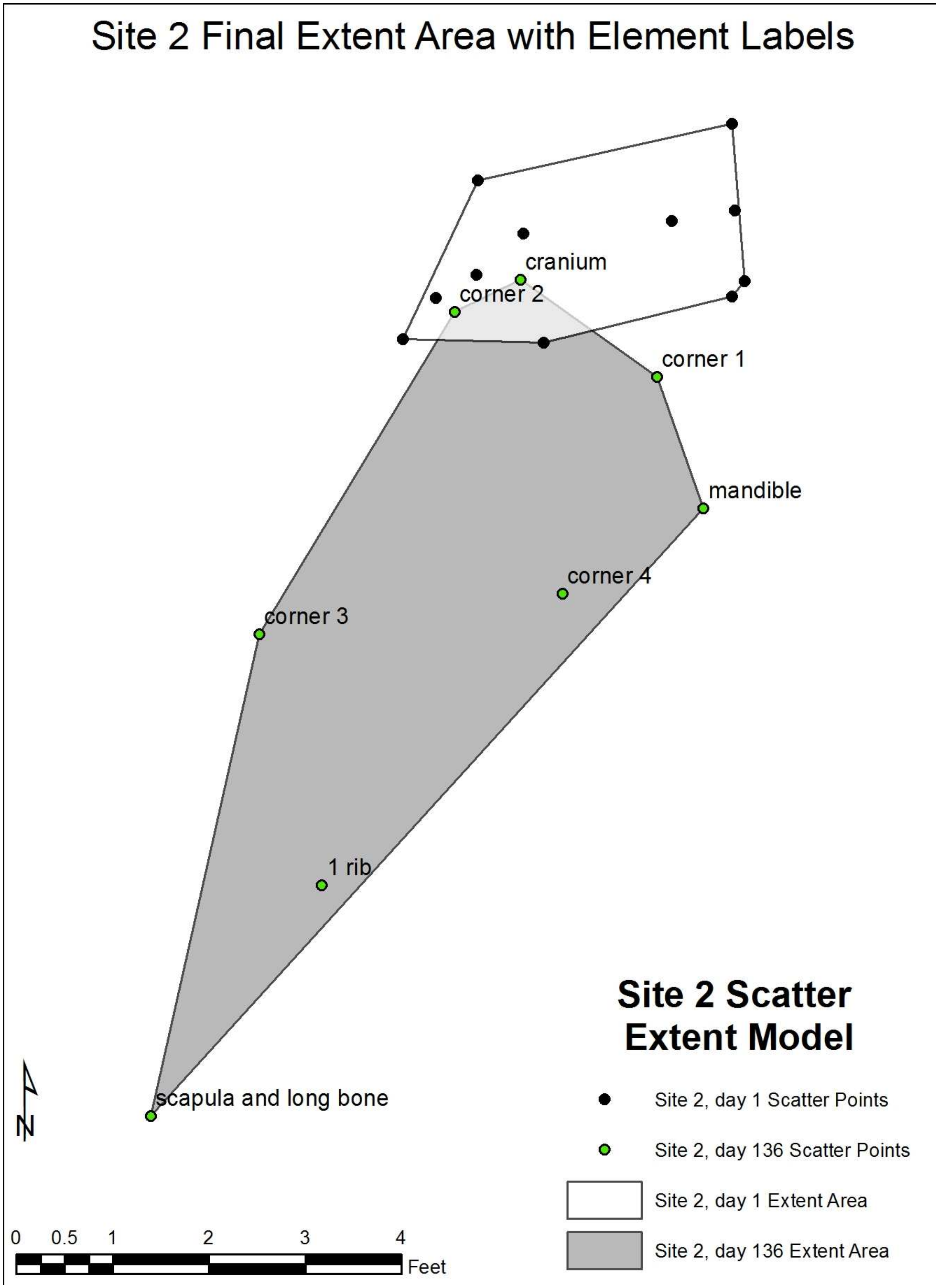

Figure 29. Site 2, final extent with elements labeled.

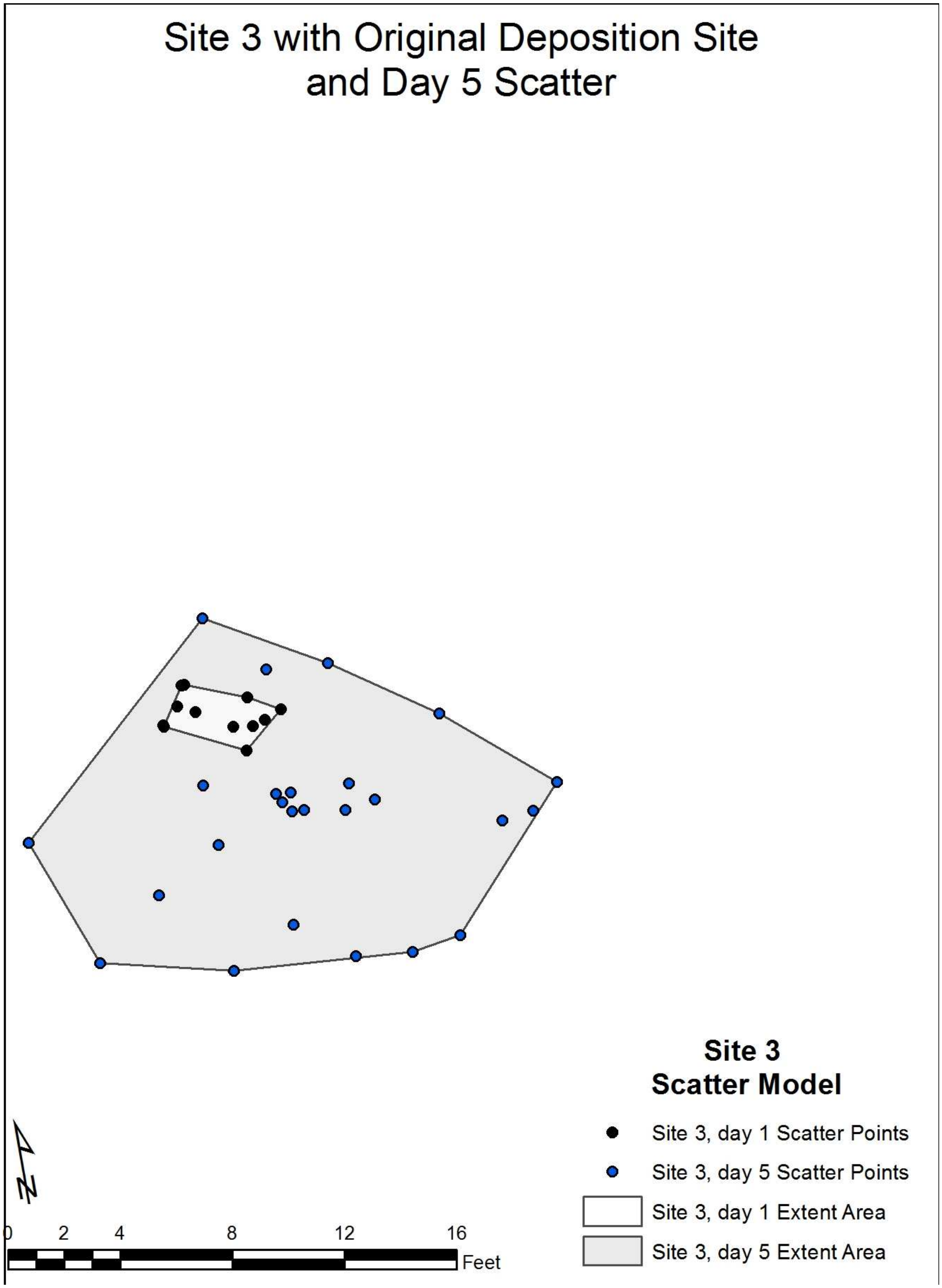

Figure 30. Site 3, day 5: scatter extent map.

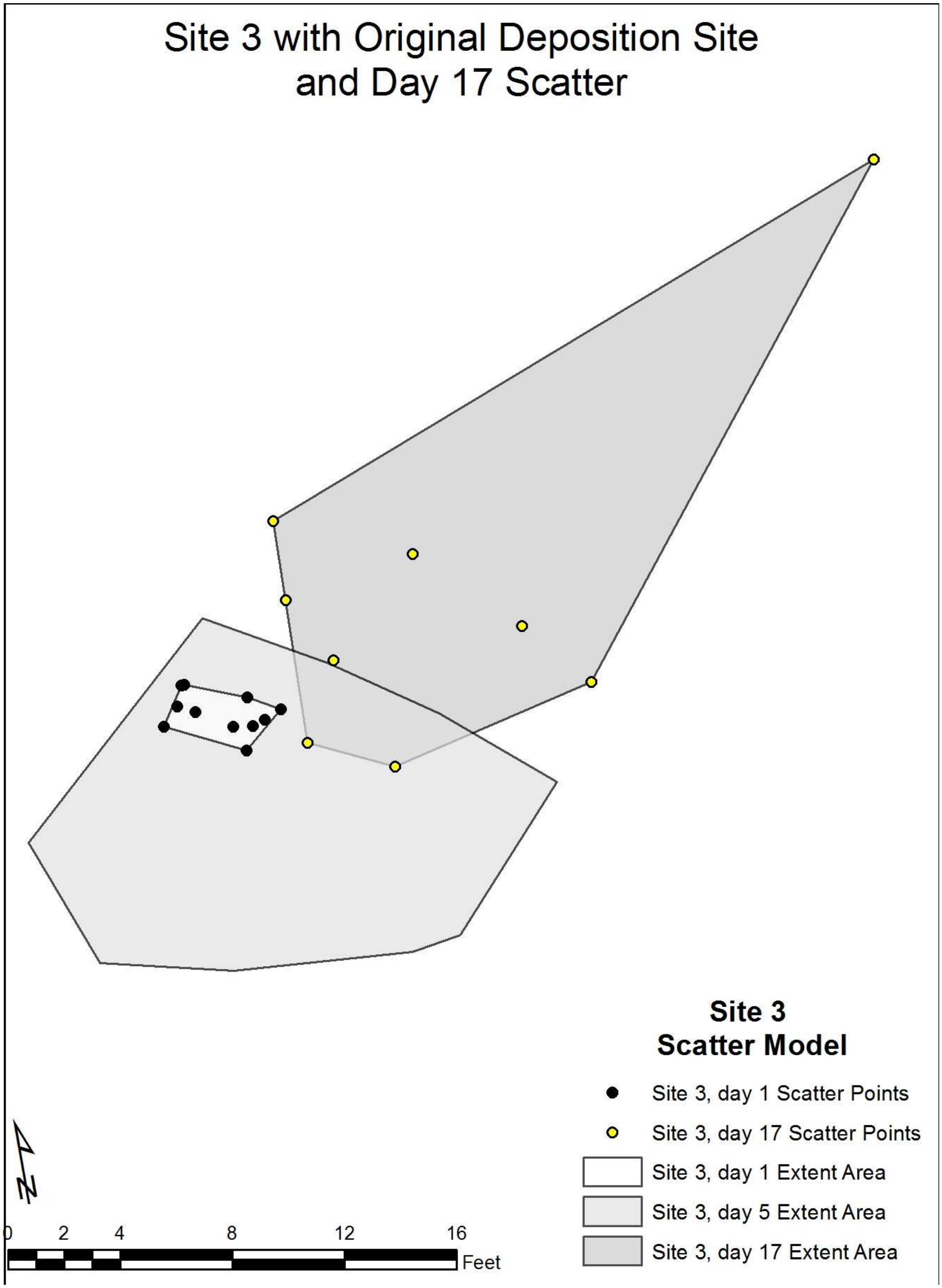

Figure 31. Site 3, day 17: scatter extent map.

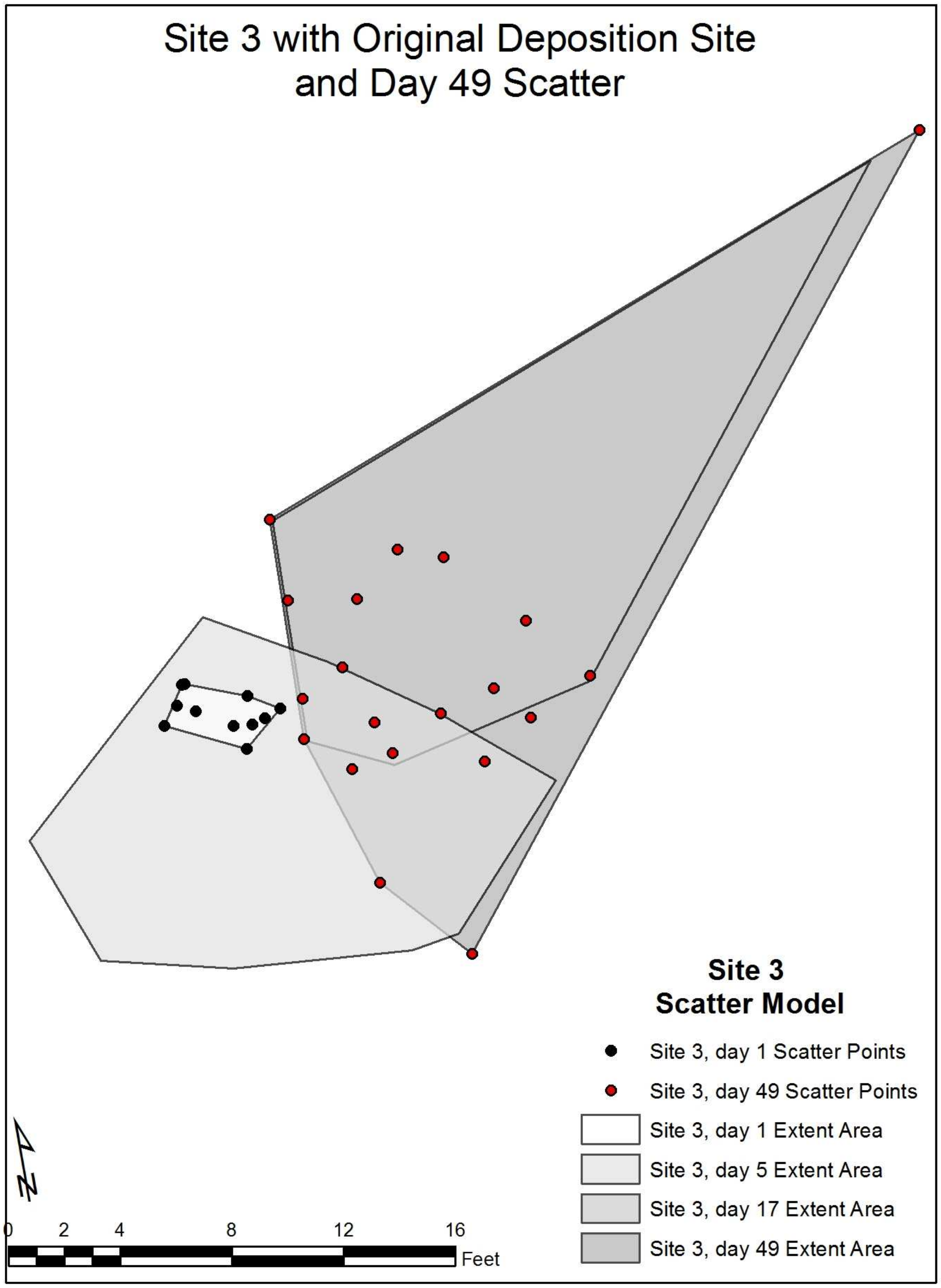


Figure 32. Site 3, day 49: scatter extent map.


Figure 33. Site 3, day 136: scatter extent map.

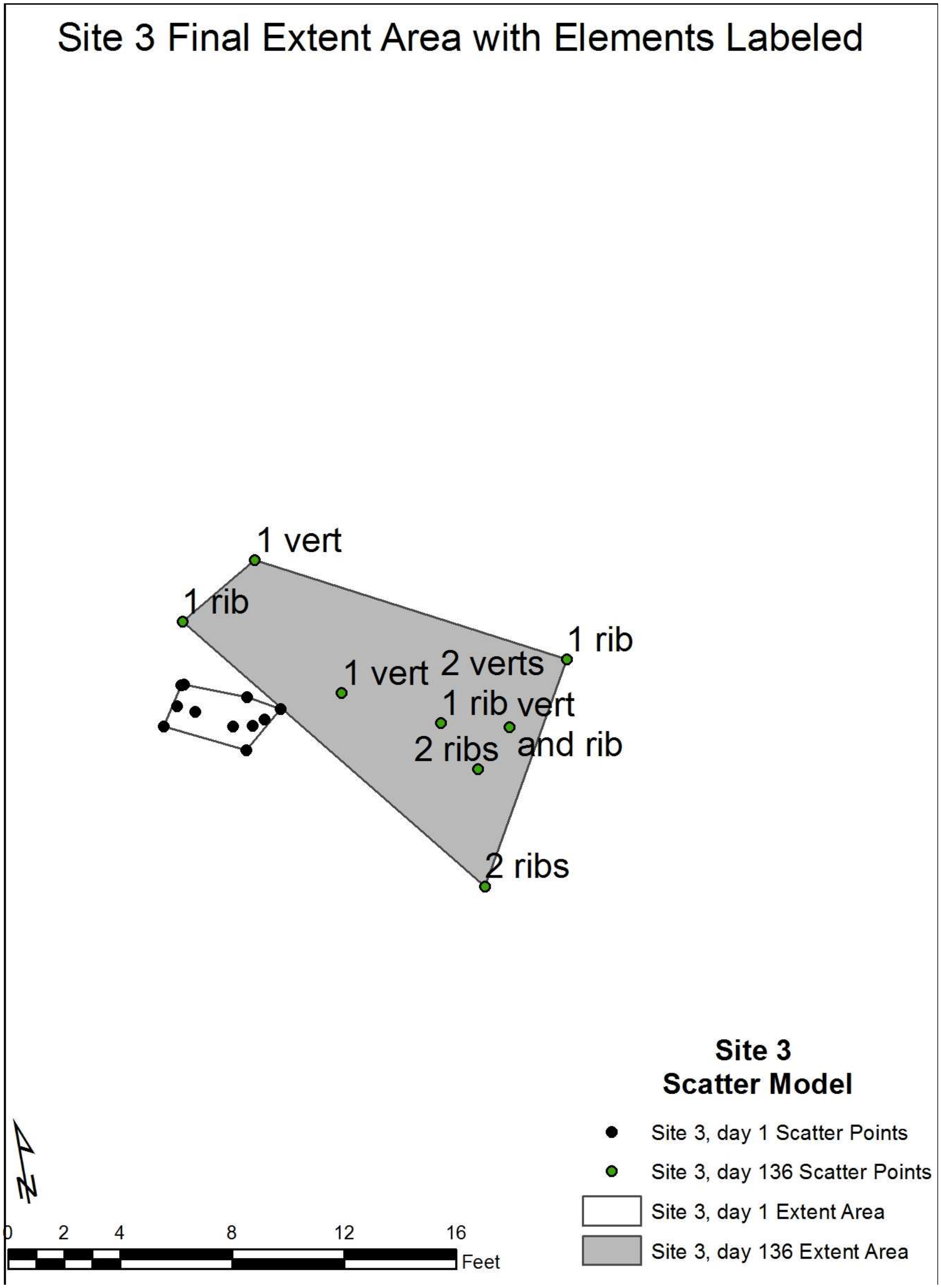


Figure 34. Site 3, final extent with elements labeled.

Each polygon created by the minimum bounding tool had its area measured for comparison over time. Another test performed, calculated the mean center of the distribution of each polygon. The change in area and mean center shifts are shown for Sites 1-3 in Tables 4-6 respectively.

Table 4. Scatter area for each mapping day and shift in the mean center for Site 1.

| Mapping Day | Scatter Area (sq. ft.) | Mean Center Shift from original Deposition (ft.) |
|---|---|---|
| 1 | 5.80 | - |
| 5 | 58.67 | 3.53 |
| 49 | 67.83 | 3.89 |
| 136 | 38.99 | 4.69 |

Table 5. Scatter area for each mapping day and shift in the mean center for Site 2.

| Mapping Day | Scatter Area (sq. ft.) | Mean Center Shift from original Deposition (ft.) |
|---|---|---|
| 1 | 5.50 | - |
| 5 | 11.57 | 4.07 |
| 17 | 21.48 | 3.88 |
| 49 | 21.92 | 3.83 |
| 136 | 19.06 | 3.74 |

Table 6. Scatter area for each mapping day and shift in the mean center for Site 3.

| Mapping Day | Scatter Area (sq. ft.) | Mean Center Shift from original Deposition (ft.) |
|---|---|---|
| 1 | 5.80 | - |
| 5 | 155.16 | 4.8 |
| 17 | 183.95 | 9.08 |
| 49 | 256.28 | 7.78 |
| 136 | 74.44 | 6.78 |

Along with the minimum bounding analysis tool, a Directional Distribution (Standard Deviational Ellipse) tool was used. This function summarizes the data into ellipses representing the direction and spread to a single standard deviation. Figures 35-37 show these ellipses maps for Sites 1-3 respectively (in the map legend ‘Eli‘ denotes ‘ellipse model’). And Table 7 displays the rotational changes and area changes of these ellipses over the course of the study. The rotational changes are represented by clockwise degrees from 0 for each ellipse.

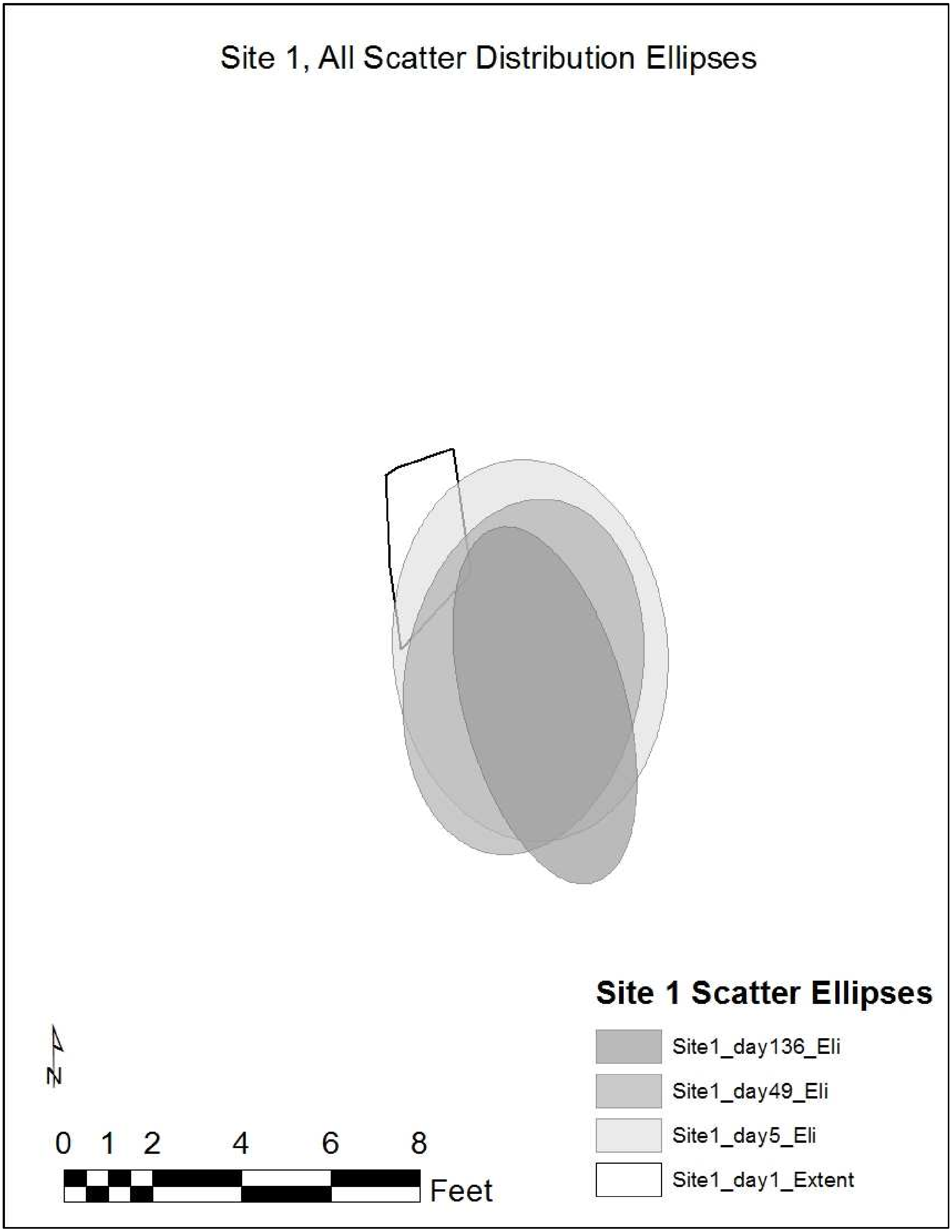


Figure 35. Directional Distribution ellipse map of Site 1.

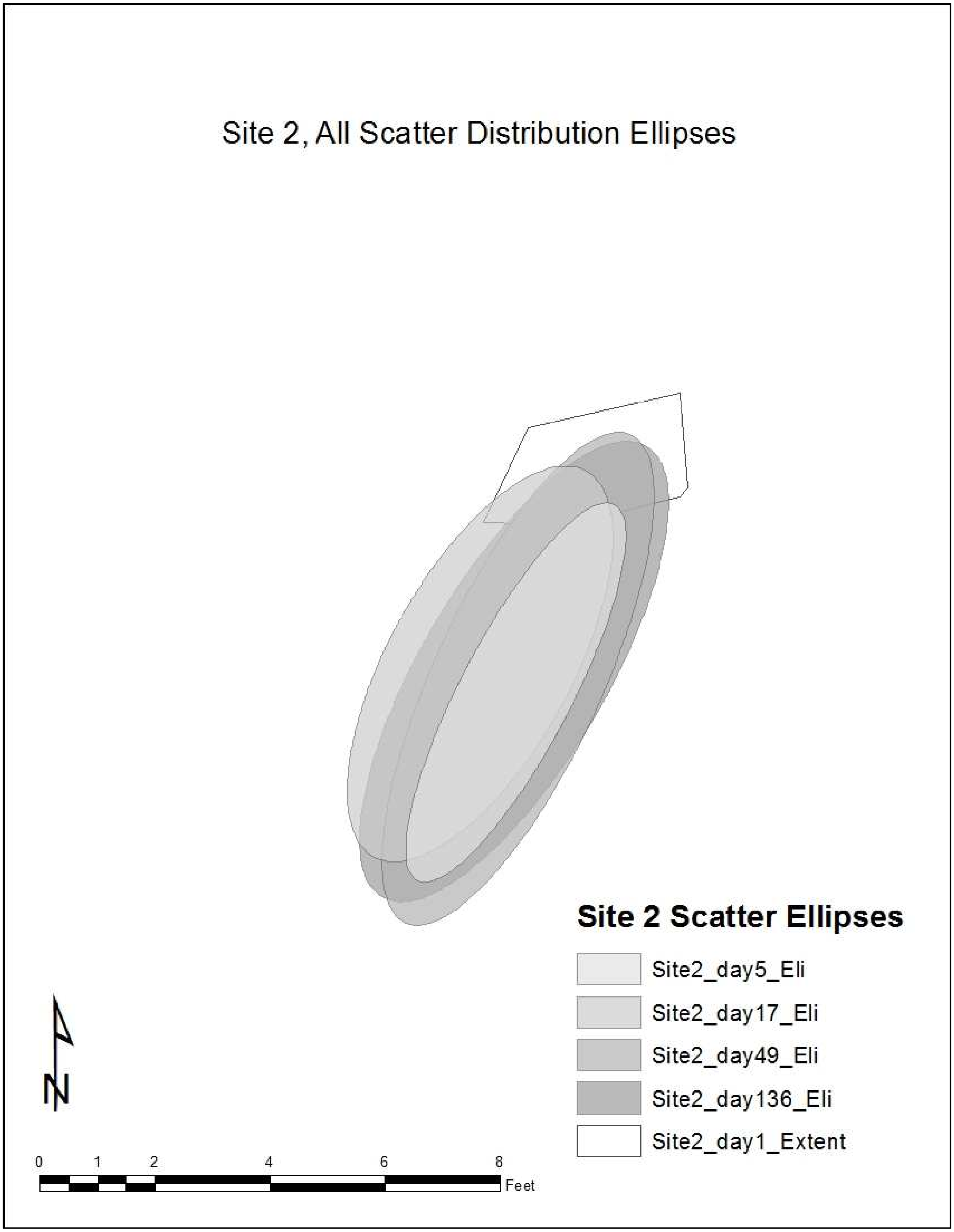

Figure 36. Directional Distribution ellipse map of Site 2.

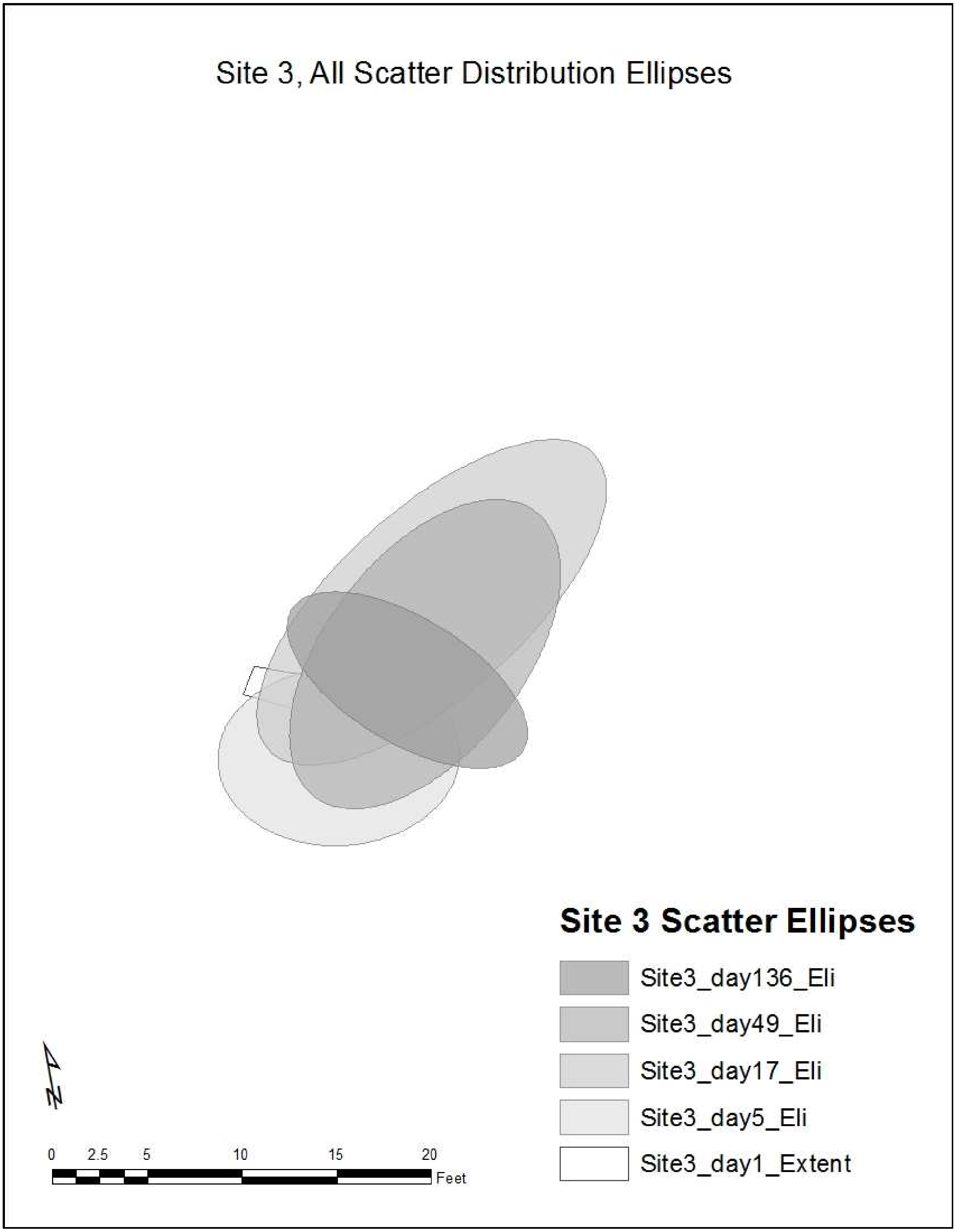

Figure 37. Directional Distribution ellipse map of Site 3.

Table 7. Rotation and Area changes for the directional distribution ellipses for Sites 1-3.

| | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|
| | Rotation (degrees) | Area (Sq. ft.) | Rotation (Degrees) | Area (sq. ft.) | Rotation (degrees) | Area (sq. ft.) |
| Day 5 | 175.15 | 41.57 | 27.64 | 11.16 | 87.13 | 94.2 |
| Day 17 | - | - | 28.77 | 19.08 | 47.89 | 179.18 |
| Day 49 | 10.52 | 33.53 | 24.82 | 21.35 | 37.95 | 155.87 |
| Day 136 | 164.64 | 23.60 | 30.39 | 22.93 | 121.28 | 73.97 |

The results of this study can be broken down into 3 categories: climatological data, the decomposition of the control specimen, and the disarticulation and scatter of the experimental specimens. The climatological data, specifically the temperature data, showed a summer that was milder than the NWS averages, with slightly lower highs and higher lows. There was also less rainfall on average except for the month of July, which had 1.35 inches above average. These climatological factors play a critical role in the decomposition process of the control specimen. The control decomposed through the 5 stages in rapid succession, more quickly than expected especially when one takes the milder weather conditions into account. In comparison to the control, the exposed specimens did not follow traditional decomposition stages because disarticulation and scatter occurred rapidly. The photographic evidence showed vultures and coyotes to be the key contributors to disarticulation and scatter. The maps of the scatters extents over time display a trend of increasing area until day 136, when the areas decrease due to the loss of skeletal elements. The size of the ellipse models compared to the convex hull models indicate an even dispersal of the remains, not a clustering around the deposition site, as the ellipses generally match the convex hull extent models in size and orientation.

# CHAPTER 5

# DISCUSSION

The purpose of this study was to determine what effects animal scavenging had on corpse decomposition rates in eastern North Carolina, and to investigate whether or not scavenging scattering events could be correlated to the postmortem interval. In this case, pigs were used as a proxy for human corpses. Based on previous research, the three exposed porcine subjects were expected to decompose and disarticulate at a faster rate than the control subject. Scavenging activity is influenced by micro-environmental differences; therefore the three exposed sites were positioned to simulate as holistic a view of the ecology of eastern North Carolina as possible. The climatological and ecological differences between eastern North Carolina and other locations of similar experiments make this project's results difficult to compare to previous research, therefore 12 forensic cases from eastern North Carolina will also be used to gain a local comparative sample.

There were a number of expectations going into this project regarding the decomposition process of the test subjects. It was expected that the control Site would decompose at a similar rate to the only other study in the region by Leone (2006). Secondly it was expected that the exposed sites would decompose to a skeletal state more rapidly than the control due to the removal of soft tissue by scavengers. Along with this second expectation, it was hypothesized that a staged decomposition sequence, like that used for the control Site, would not accurately describe the sequences of the exposed pigs. Finally, it was predicted that the scatter patterning and distance moved over time could be positively correlated to PMI based on the results of studies by Kjorlien et al. (2009) and Haglund (1997).

*Decomposition of the Control Specimen*

It was vital to this study to have a control specimen to compare with the experimental specimens. This control was meant to simulate the effects of climatic variables and insect activity alone on a surface deposition scene. It was originally postulated that this control subject would follow a similar decomposition process as a previous experimental study of this nature. Leone (2006), investigating the differences in decomposition rates at sunny versus shaded sites at the WRC, found that the sunny sites, similar to the location of the control specimen in this study, decomposed to full skeletonization in 123 days. Leone (2006) distinguished four decomposition stages on the sunny site specimens. A four-stage model is not necessarily indicative of a differing timeline; it is simply dividing the postmortem changes differently. Table 8 shows a comparison between decomposition rates at this experiment's control Site and the sunny from Leone (2006).

Table 8. Control Site in this study compared to Leone's (2006) sunny site at the WRC.

| Control Site | | Sunny Site from Leone (2006) | |
|---|---|---|---|
| Stages of Decomposition | Duration (In days since death) | Stages of Decomposition | Duration (In days since death) |
| Fresh | 0-2 | Fresh | 0-2 |
| Bloat | 3-5 | Bloating | 3-12 |
| Active Decay | 6-9 | Decay | 13-122 |
| Advanced Decay | 10-15 | | |
| Skeletonization | 16-136+ | Skeletonization | 123-157+ |

The control remains decomposed at a slightly faster rate than the exposed remains from Leone (2006), although no definition was given in her 2006 research regarding the definition of skeletal. My research used 50% of the skeletal elements showing as the definition of a skeletal state. Via personal communication, it was revealed that Leone (2006) categorized her specimen as skeletonized once 90% of its elements were exposed. As shown in the photographic evidence within Leone (2006) a level of skeletonization comparable to my study would have occurred in Leone (2006) at approximately day 25. The more rapid decomposition of my control specimen was not the result of abnormally high temperatures, as the daily high temperatures for this experiment were 14.15 degrees F lower than averages for the exposed site in Leone (2006) who's experiment spanned from August 2005 to January 2006. The majority of the morphological changes to the control happened within the first 15 days, during the month of June, which had just below average rainfall. Only July, well after the drastic decomposition of the control, had above average rainfall. The only marked difference in this study and Leone (2006) that this experiment began in mid-June, while the 2005 research started in August, which has roughly equivalent temperatures to June (see averages presented in Figure 3). Although the studies begin at different times of year, the marked difference in decomposition speed is certainly a noteworthy result. However dissimilar these current results are from Leone's (2006) previous research, they still serve as a critical benchmark by which to compare the exposed remains in this study as well as highlights the incredible variation within the decomposition process.

*The Experimental Specimens' Decomposition*

It was postulated that the exposed remains would decompose far more rapidly than the control remains due to the dramatic decrease of soft tissue mass expected with animal scavenging. In fact, the standard decomposition stages used for the control specimen could not be applied to the scavenged remains. The exposed remains essentially progressed from the fresh stage directly to scattered and skeletal. Scavenging vultures punctured the abdomen within hours of deposition on all sites, preventing bloat from occurring. It would seem appropriate then to adopt a sequence related to body part manipulation by scavengers, whether it is soft tissue evisceration, skeletal disarticulation, or scattering. Dividing such a sequence by body part or skeletal element would allow comparison between the three exposed sites as well as documented forensic cases involving scavenged remains. Table 9 displays the scavenging sequences for all three experimental sites from this study compared with a system developed by Haglund et al. (1989). This system, which can be adopted easily for pig remains, allows researchers and investigators to quantify scavenger alterations and scattering events separately from the standard decomposition sequences. Scavengers removed the vast majority of soft tissue within the first 3 days at Sites 1-3, and they reached stage four by day 8, 5, and 7 respectively (Haglund et al. 1989). The exposed remains reached full skeletonization far more quickly than the control Site, as was expected, based on previous research (Reeves, 2009). Although scavenging events do follow a rough pattern: evisceration of the abdomen, disarticulation and scattering of vertebrae and ribs, and removal of the hind legs and cranium, followed by slow dispersal and natural disarticulation of all articulated elements, there is limited evidence to suggest that scattering patterns can be positively correlated to PMI in any quantifiable sense. Each site's unique microenvironment influenced the disarticulation and scatter of the remains. Site 1, being located in an open field, but surrounded by taller grasses, led to a rapid disarticulation by vultures, but a small and contained scatter extent. Site 2, situated in a smaller clearing surrounded by heavy underbrush was even more enclosed than Site 1. Site 2, because of being so enclosed, showed slower initial disarticulation and scatter, but a similarly small scatter area to Site 1. Site 3, with both the most exposure and the prevalence of flooding, had the largest scatter area, but disarticulated at a similar rate to Site 2. The flooding appeared to transport the remains minimally, but greatly influenced the scene by obscuring them. As the swamp area would dry between flooding events, the remains would get stuck in the drying mud, making locating and identifying difficult. Analysis of the spatial data along with this disarticulation and decomposition data shows a general trends in scatter patterning.

Table 9. Experimental Scavenging Sequence compared to stages from Haglund et al. (1989)

| Site 1 | | | Site 2 | | | Site 3 | | |
|---|---|---|---|---|---|---|---|---|
| Duration (In days since death) | Morphological Changes | Haglund et al. (1989) Stages | Duration (In days since death) | Morphological Changes | Haglund et al. (1989) Stages | Duration (In days since death) | Morphological Changes | Haglund et al. (1989) Stages |
| 2 | Abdomen Opened and initial removal of internal organs | 0 | 2 | Rib cage exposed, initial organ removal | 0 | 2 | Anus, nose, and eyes removed | 0 |
| 4 | All organs Consumed, disarticulated cranium, lower limbs disarticulated from Axial skeleton and scattered, section of articulated vertebra scattered | 1 | 4 | Cranium disarticulated, mandible scattered, axial skeleton and limbs still articulated but limited soft tissue remained | 1 | 4 | Ribs scattered, and all internal organs removed | 1 |
| 5-7 | Lower limbs dragged further | 2 | 5 | Articulated rib cage and vertebral column scattered | 4 | 7 | Articulated hind limbs removed from deposition site, vertebra and rib scatter | 2 |
| 8-present | Natural disarticulation and bleaching | 4 | 6-10 | Limited movement of hind limbs | | 11 | Cranium removed from site | 4 |
| | | | 11-present | Natural disarticulation and bleaching | | 12-present | Natural disarticulation and bleaching | |

*Spatial Analysis*

The convex hull maps along with their corresponding area tables show a trend of rapid outward expansion over the first 49 days and by day 136 a decrease in scatter extent. This is likely due to thick vegetation growth that obscures the study sites and makes locating remains difficult or impossible. The directional distribution maps of Site 1 and 3 indicate a similar pattern, while Site 2's area for this model increases with each mapping day. Site 1 maintained a direction of spread that only shifts by approximately 20 degrees over the study period. Site 2 maintained a rotation of less than 4 degrees over the study, indicating a unilineal spread pattern. Site 3, with its massive loss of elements between day 49 and 136 has a drastic change in the direction of spread as well as loss of area.

*A Comparison to Previous Casework*

The critical hypothesis of this research was that scattering patterns could aid in the estimation of the postmortem interval. By comparing the scatter patterns seen in this study to forensics cases from eastern North Carolina, this research can be placed in local context. Twelve forensic cases that showed signs of animal scavenging from eastern North Carolina and were mapped in the field were subjected to the same ArcGIS mapping models as the experimental remains of this study. The PMIs established by the law enforcement, based on missing person's reports for these 12 cases, range from less than one year to approximately 14 years. The maps of cases 5, 7, and 12 are shown below (Figures 38-40). Case 7 has a PMI of 0.3 years, case 5 has one of 3.6 years, and case 12 has one of 14.17 years. These cases represent the minimum and maximum PMI as well as the case with the closest PMI to the mean for this sample (3.12 years).

Appendix C contains all 12 maps from these cases. The maps themselves show both a minimum bounding convex hull model of the data as well as a standard deviation ellipse model.

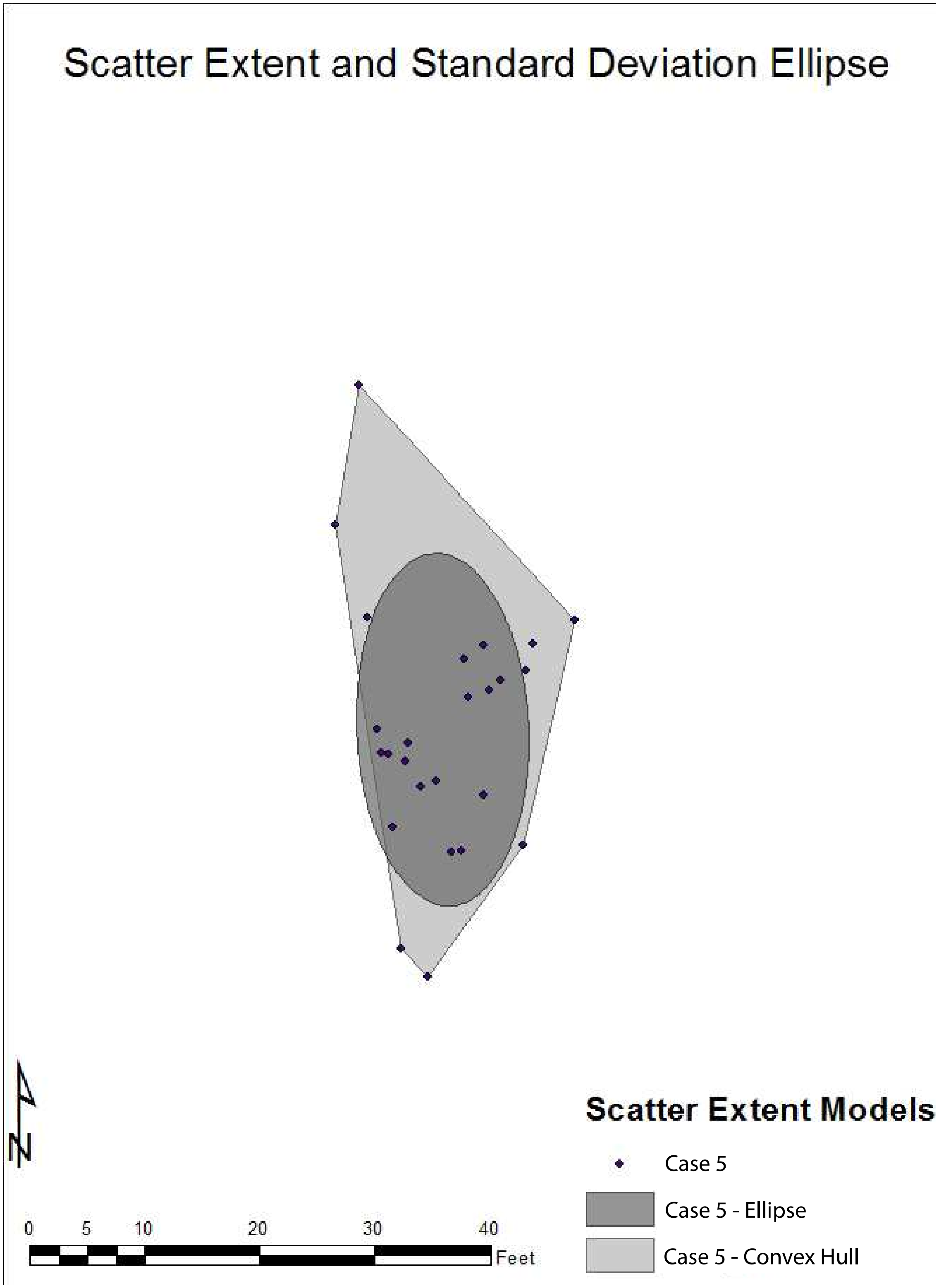


Figure 38. Scatter Extent models for case 5, which has a PMI of 3.6 years.

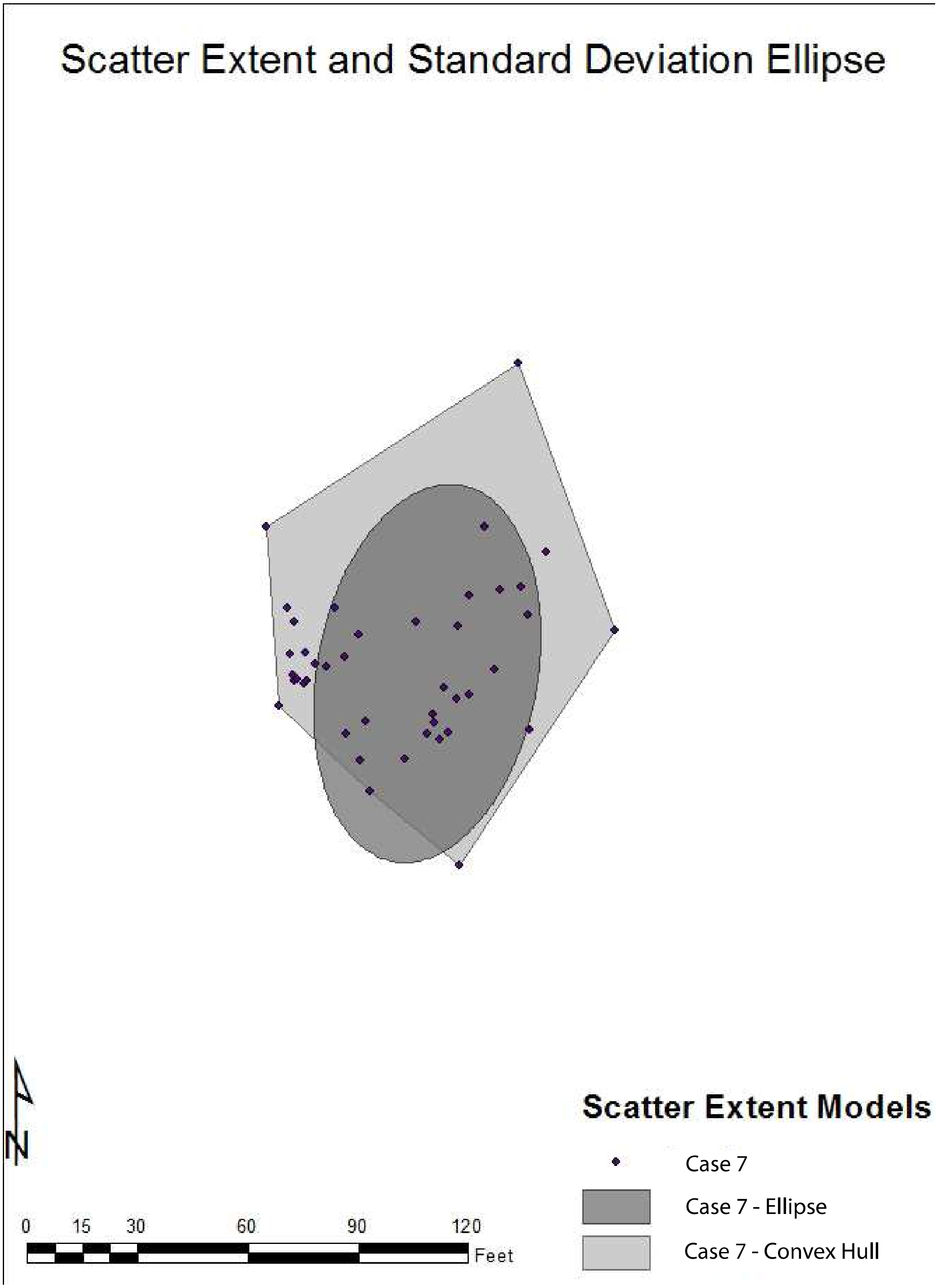


Figure 39. Scatter Extent models for case 7, which has a PMI of 0.3 years.

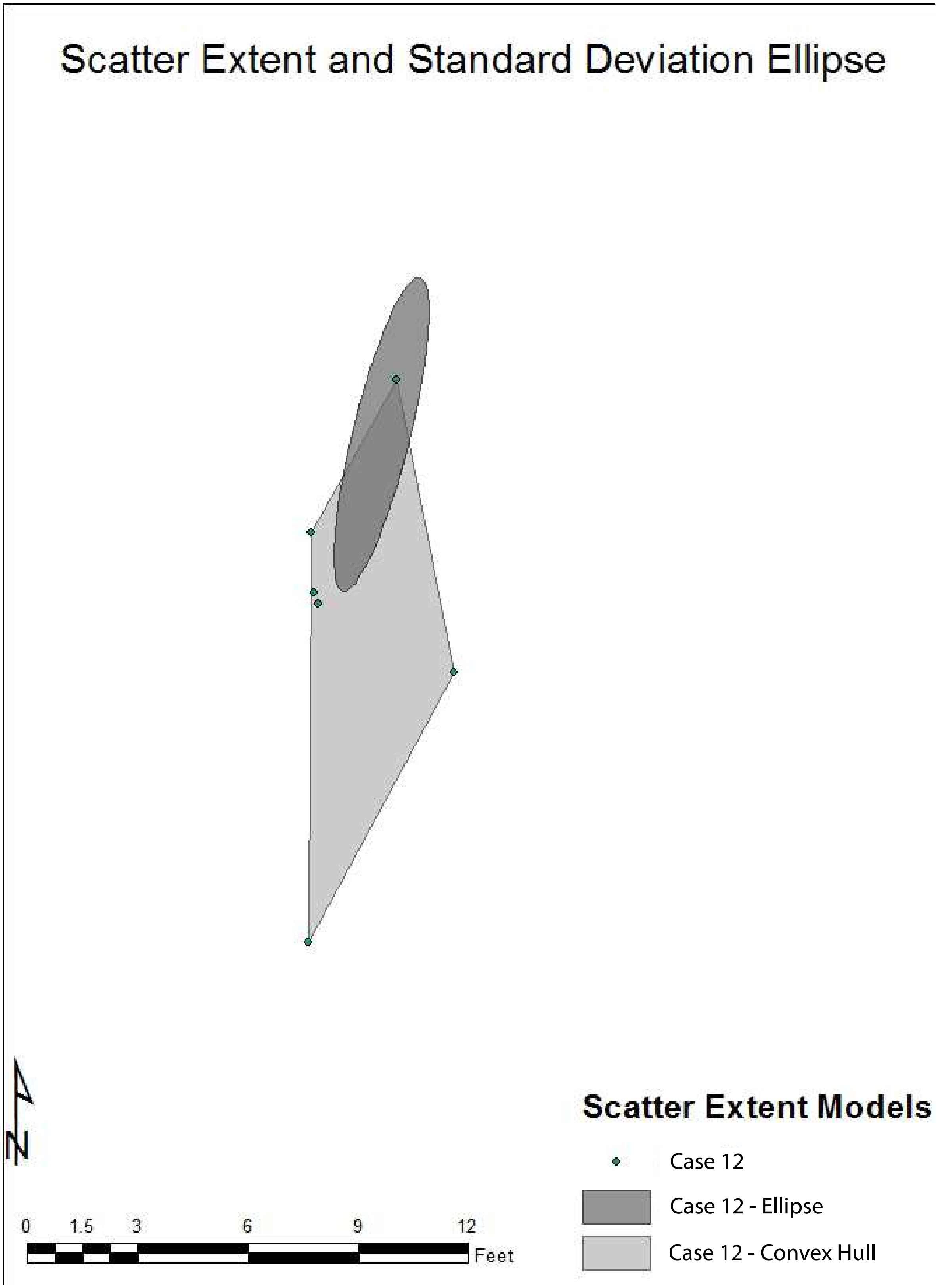


Figure 40. Scatter Extent models for case 12, which has a PMI of 14.17 years

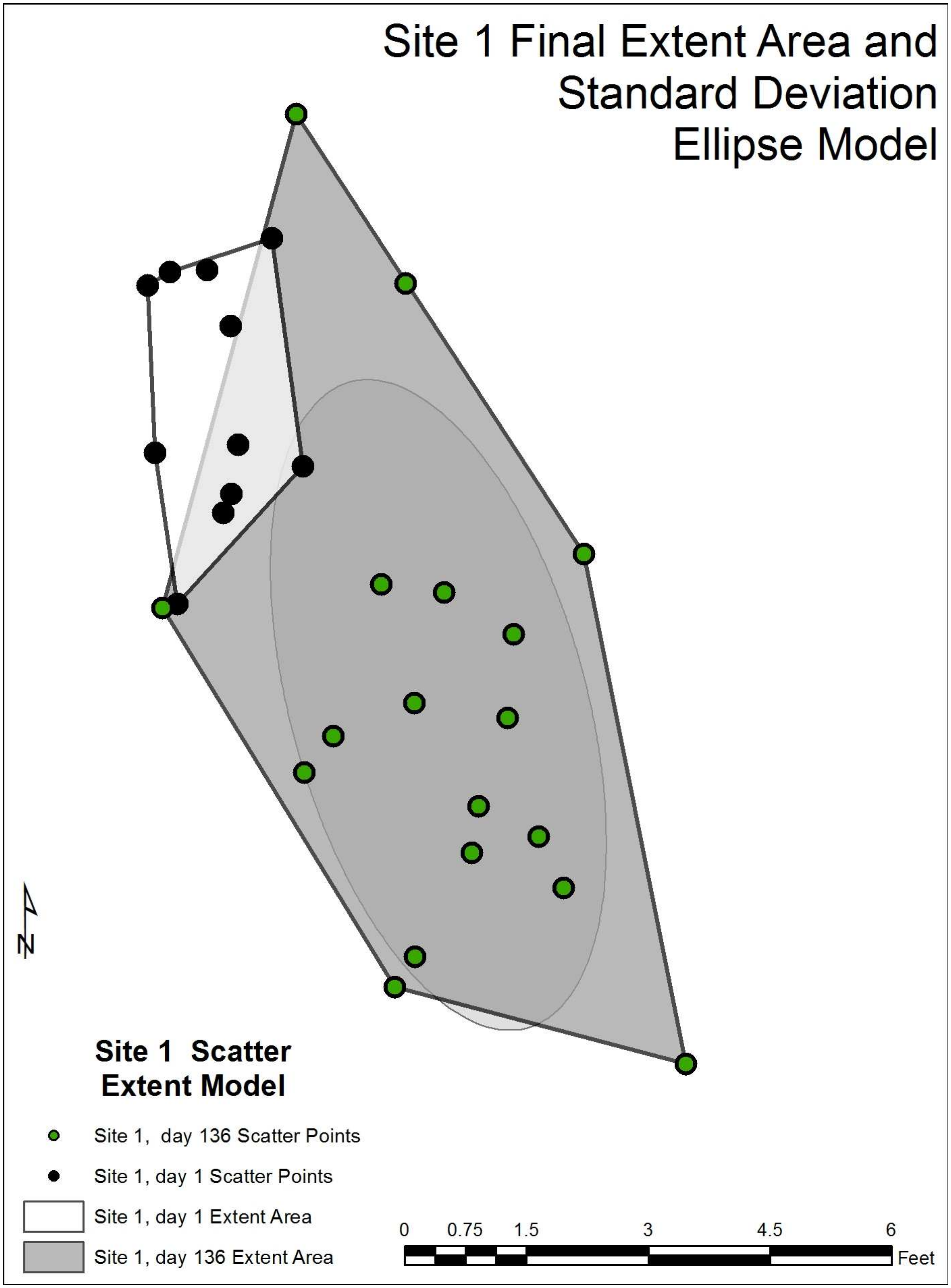


Figure 41. Site 1, day 136, Scatter extent and ellipse model.

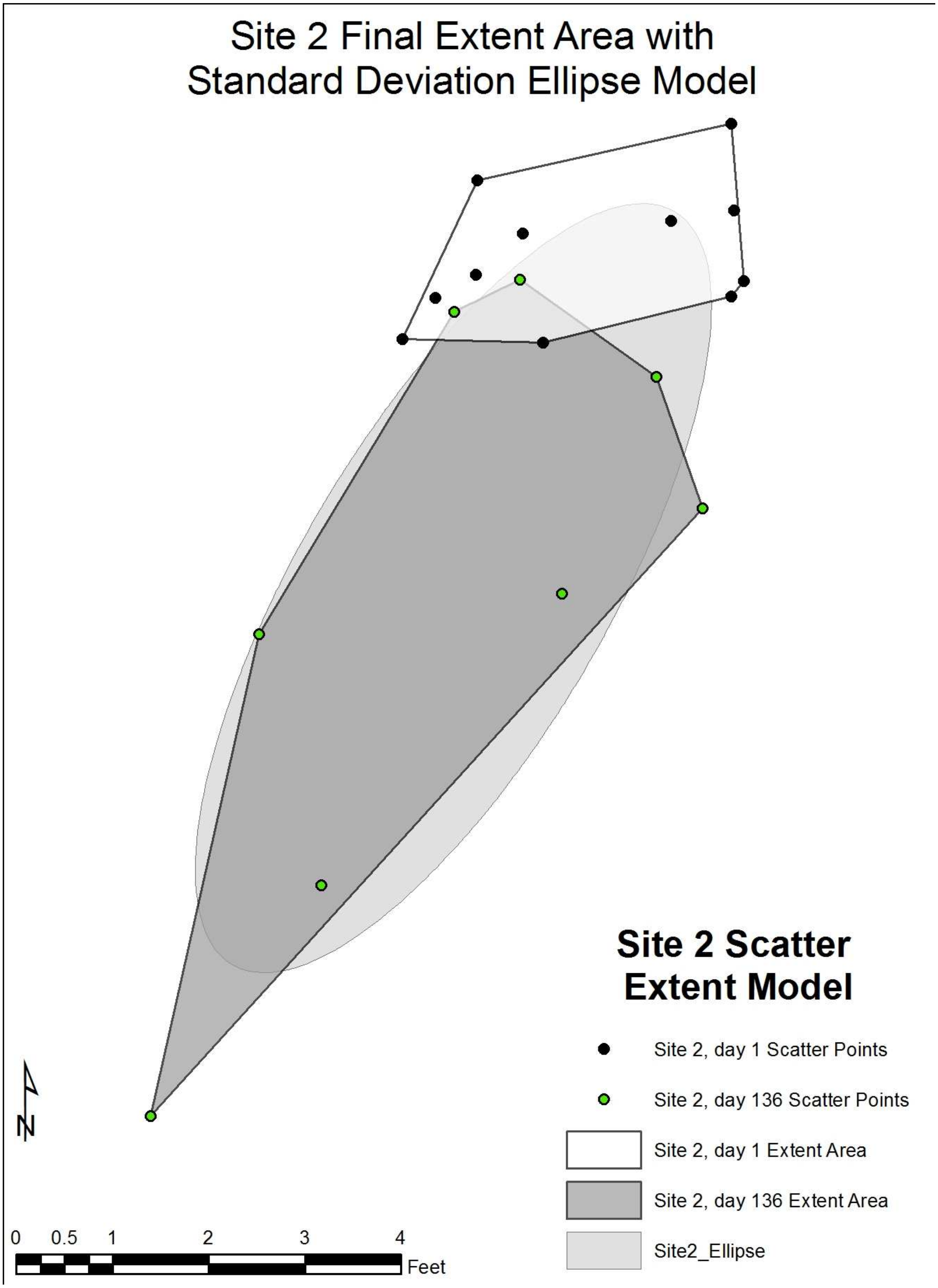


Figure 42. Site 2, day 136, Scatter extent and ellipse model.

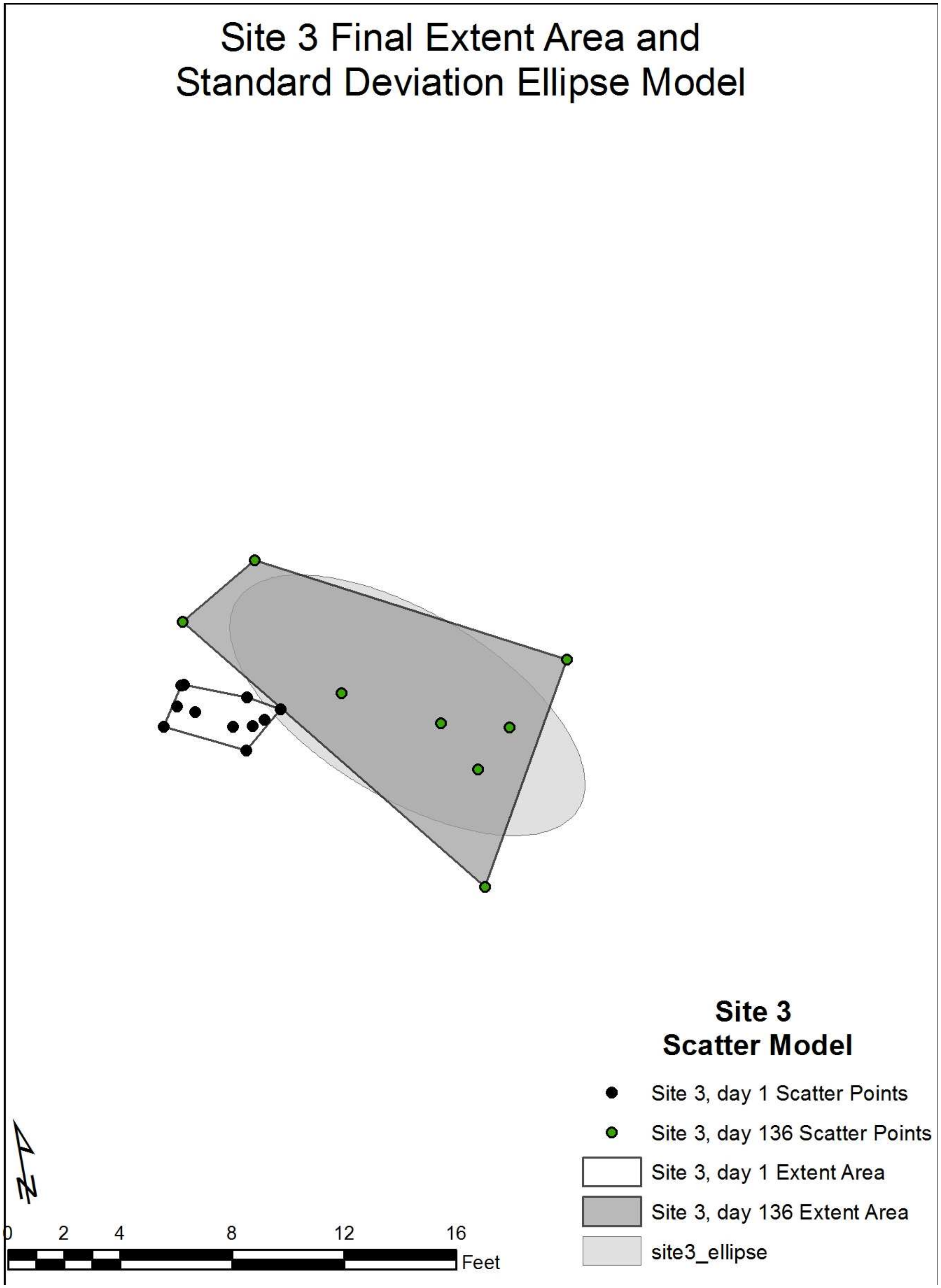

Figure 43. Site 1, day 136, Scatter extent and ellipse model.

The trends in these data are markedly different from the trends seen in the experimental study. The convex hull and ellipse model extent areas are presented in Table 10, below. There is no pattern to the areas when sorted by increasing PMI. Linear Regression models, run in the program R, indicate no significant relationship between scatter area and PMI or ellipse area and PMI. Linear regressions for both the convex hull and ellipse models are shown below (Figure 41 and 42)

Table 10. Convex hull and standard deviation ellipse model areas.

| Case Number | PMI (Years) | Convex Hull Extent Area (sq. ft.) | Standard Deviation Ellipse Area (sq. ft.) |
|---|---|---|---|
| 1 | 1 | 11.35 | 2.04 |
| 2 | 2 | 3364.72 | 684.91 |
| 3 | 1.92 | 36.27 | 17.33 |
| 4 | Unknown | 888.99 | 723.02 |
| 5 | 3.6 | 604.29 | 359.30 |
| 6 | 0.7 | 1441.95 | 235.52 |
| 7 | 0.3 | 7883.45 | 4895.14 |
| 8 | 6.7 | 1074.89 | 182.34 |
| 9 | 5.1 | 238.21 | 63.83 |
| 10 | 1.6 | 161.89 | 109.36 |
| 11 | 0.3 | 23770.89 | 12903.99 |
| 12 | 14.17 | 34.12 | 10.66 |

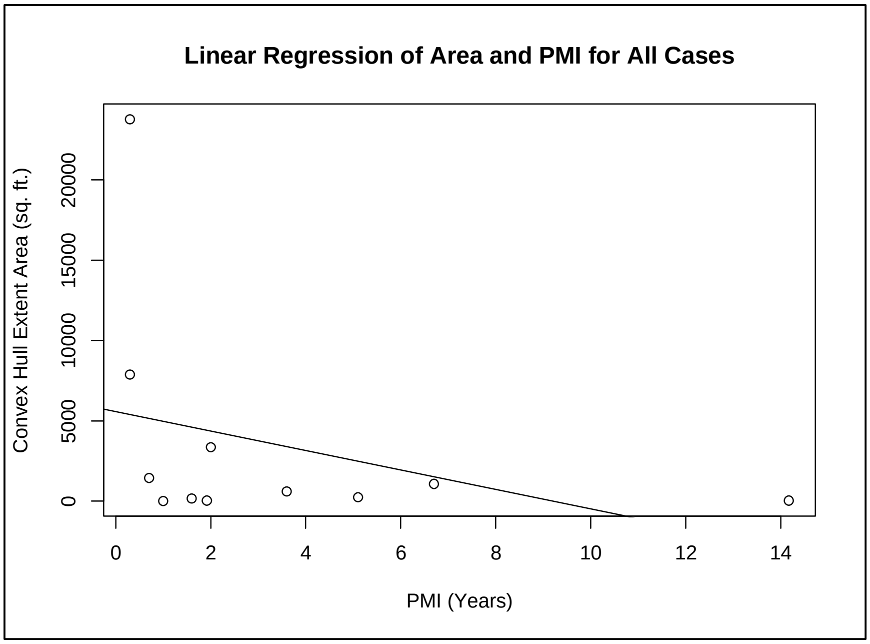


Figure 44. Linear Regression for convex hull area and PMI. An adjusted $R^2$ value of 0.0252 indicates that the linear regression presented accounts for only 2.52% of the variance in the data, therefore the linear relationship between the data points are not significant.

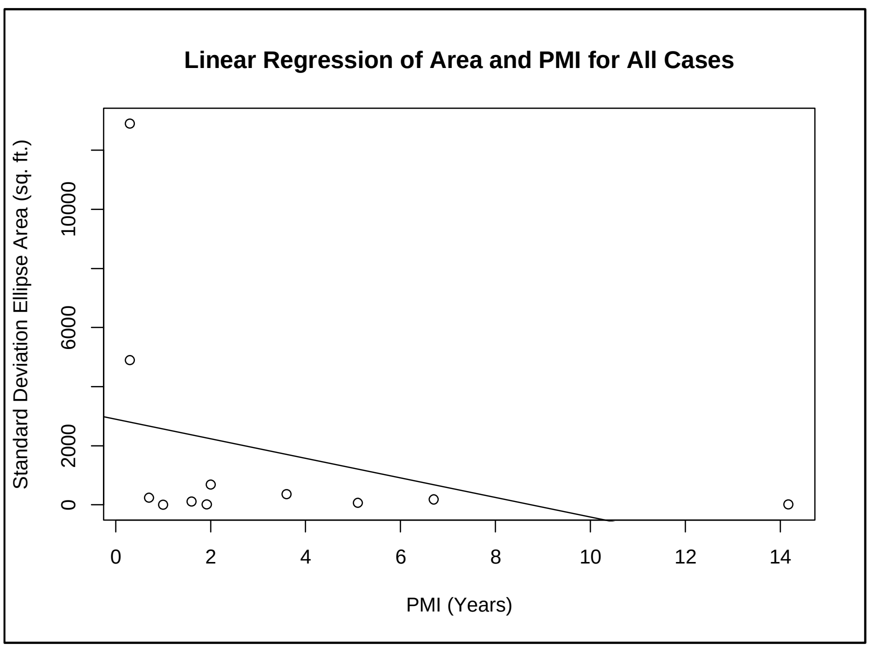


Figure 45. Linear Regression for the ellipse model area and PMI. An adjusted $R^2$ value of 0.020407 indicates that the linear regression presented accounts for only 2.04% of the variance in the data, therefore the linear relationship between the data points are not significant.

One immediately noticeable difference between the twelve eastern North Carolinian forensic cases and the data collected in this current research is the dramatically larger scale of the scatter extents found in the casework. Potentially this is due to the much longer PMIs established in these cases. The scale of police investigations is also a critical factor; they have full-scale recovery teams with multiple people searching a wider area. For the sake of a manageable area in my research, remains located outside of my search area were deemed lost. Another marked difference between my research and the case studies is the relationship between the extent areas and their standard deviations. In this current research the two areas overlapped and were an approximation of each other's size, while the forensic case maps indicate a drastic difference in the two (Table 11). Figures 41-43 display the final scatter extents and ellipse models overlaid on one another for Sites 1-3 of this research. In the casework, the standard deviation areas are noticeably smaller than the total extents. This indicates that although some elements scattered and were located far from the deposition site, the majority of the elements were clustered at the deposition site. This differs from this current research where elements seemed to scatter and expand in larger quantities, but to a smaller overall area, as shown in the similar size of the total extent areas and ellipse areas.

Table 11. A comparison between the scatter areas between the current research and forensic casework.

| | Current Research | | | Forensic Cases | | |
|---|---|---|---|---|---|---|
| | Site 1 | Site 2 | Site 3 | Case 5 | Case 7 | Case 12 |
| PMI (years) | 0.38 | 0.38 | 0.38 | 3.6 | 0.3 | 14.17 |
| Final Extent Area (sq. ft.) | 38.99 | 19.06 | 74.44 | 604.29 | 7883.45 | 34.12 |
| Standard Deviation Ellipse (sq. ft.) | 23.60 | 22.93 | 73.97 | 359.30 | 4895.14 | 10.66 |

A comparison between these forensics cases and the data from this experimental study suggests that scavenging animals are a chaotic variable in the study and investigation of surface deposition sites. As has been previously stated, there are numerous factors that play roles in the decomposition of a human body, and each case is remarkably different. Comparing this work to previous research it is possible illuminate larger more general trends in scavenging patterns as they relate to the estimation of PMI.

*A Comparison to Previous Research*

Haglund et al. (1989) acknowledges that estimating PMI based on scavenger activity is challenging. There are enumerable factors that can influence decomposition rates and scavenger activity, and each of these variables makes each case remarkably unique. Haglund et al. (1989) focused on cases from the Pacific Northwest, a drastically different environment than the Southeastern United States. They found that total disarticulation would occur in “as little as two months” (Haglund et al. 1989: 604), whereas this research found total disarticulation in less than two weeks. Research conducted in central Texas by Reeves (2009) found that vulture activity alone could produce a fully skeletonized pig specimen in as little as two days (Reeves 2009:527). Spradley et al. (2012), finds that vultures can reduce human remains to full skeletonization in 5 hours in central Texas, a far more rapid duration than any other study. In the Central Texas environments described by Reeves (2009) and Spradley and colleagues (2012), remains progress more quickly to skeletonization than in eastern North Carolina, which found minimal soft tissue left by day 4 on average between the three sites. Reeves (2009) recorded far more vulture activity at one time than were present in this research. The relative scarcity of food sources compared to large scale of Central Texas could be a factor in the voracity of scavenging activity. Comparatively, eastern North Carolina, offers a richer and more condensed ecosystem for feeding, which could have resulted in less aggressive feeding by vultures compared to Reeves (2009).

Other studies have had skeletonization rates similar to my research. Dabbs and Martin (2013) found that vulture activity could reduce specimens to full skeletonization in 7 days, in a study conducted in southern Illinois in August 2011, a similar finding to this study's results. Morton and Lord (2006) studying the effect of scavengers on child-sized remains in Virginia found the most similar results to this study. In their study of child-sized pig remains, they found scavenger activity reduced the specimens to skeletal elements by day 5 (Morton and Lord 2006: 479). Similar to Haglund et al. (1989), they find that patterns are difficult to establish in scavenger scattering events, as each incident is unique, based on numerous environmental factors. Manhein et al. (2006), in a study of 36 cases from Louisiana, found no directional trend for element dispersal. Here, this randomness is seen in the scatter of Site 3, but both Sites 1 and 2 show some directional patterning. This is due to the physical confines of Sites 1 and 2, which were delineated by tall grass and brush, respectively, whereas Site 3 is not so enclosed. Scavenging activity as an indicator of PMI should be used with caution only for the most general predictions. This study found that ribs and vertebra were removed first, ostensibly for scavengers to gain access to the internal organs of the abdomen, but these same elements were scattered the smallest distance. Kjorlien et al. (2009) finds a similar result in their work in Alberta, Canada, as does Haglund (1997). Although the ribs and vertebra did not get scattered far, they were also the quickest remains to become lost due to flooding and overgrowth of vegetation, due to their transportability compared to other elements. Although figures 24, 29, and 34 display numerous ribs and vertebrae present, that is only due to their large quantity compared with other bones. In this study, the spread of the remains was often influenced and contained by natural boundaries like thick brambles or high grasses. There was also evidence, at Site 2, of the remains being dragged away, and then back to the deposition site, making scatter over time appear minimal.

The forensic casework as well as previous research in the field provides a local and regional contextual framework for the results presented here. There were marked differences between the scatter extents found in the forensic casework and this research. Because these cases were located in eastern North Carolina, it can be assumed that similar scavenging animals affected the scenes, as vultures and coyotes are common not only in eastern North Carolina, but the entire eastern seaboard. Without knowing specifics about the season in which death occurred, or the deposition sites' particular microenvironments it is difficult to say exactly how their scatter extents compare to the results of this study. A comparison to the literature shows that general patterns such as were found in this research are common, but more specific correlation is hard to come by. This again is due to the large impact of minute changes in environments at each and every surface deposition site

# CHAPTER 6

# CONCLUSION

The goal of this research was to identify how scavenging activity of a corpse influences decomposition rates, and whether or not these scatter patterns could aid estimations of the time since death. It was assumed that the control specimen would decompose at similar rates to the previous study at the WRC (Leone 2006), and that all the exposed cases would not progress through traditional decomposition stages (Payne 1965). Mapping the distribution of the scattered remains over the course of the experiment allowed for interpretations to be made across both space and time, in an attempt to correlate scatter distance with PMI.

Scavenging appears to be chaotic and sporadic, with no positive association with PMI, although some important trends in the scatter patterns presented themselves. The scatter areas at each site reach a maximum by day 49 and then decrease in size by day 136, presumably due to loss of elements by overgrowth vegetation. This result can aid law enforcement during body search and recovery efforts. A trend of evisceration of the abdomen within the first two days, and disarticulation of the vertebra and ribs over days 4-7, followed by removal of the hind limbs and cranium from days 5-11, is completed by day 11 at which point the remains in this study naturally disassociate and bleach in the sun. The order and distance in which most elements were removed, however, was sporadic, although photographic evidence suggests ribs and vertebra are removed first but scattered least, which is corroborated by research from Kjorlien and colleagues (2009) and Haglund (1997). Although this current research suggests that scatter patterning is not quantitatively indicative of the PMI, it is important to note that creating disarticulation-modified decomposition stages, as laid out by Haglund et al. (1989) and scatter-pattern maps can help researchers better understand the processes that act on remains in a real world setting. Also using the 49-day maximum area concept seen in this research will aid in predicting scatter areas and making search and recovery efforts more efficient.

The stages of decomposition for a control specimen do not accurately reflect most actual body dumps or surface deposition sites, because scavengers play a massive role in the decomposition process; therefore studies such as this are critical in establishing new protocols for determining the PMI of scavenger-modified remains. Although the methods used in this experiment were well established, they were tested in a new environment and can be considered a critical achievement of this research. The motion-sensing cameras allowed for the results of the mapping to be checked against time stamped photographic evidence, and in some cases, helped retroactively adjust some mapping errors. Also, on one occasion soft tissue remains were scattered a few meters away, then, hours later moved back to the original deposition site; something that mapping did not pick up, but the cameras did.

Micro-environmental variables make each case unique and make interpretations of the scenes difficult to conceptualize into patterns, but general sequences of disarticulation and scatter were noted. Another valuable conclusion of this research is the control specimen's rapid decomposition. The control remains decomposed at a highly accelerated rate compared to previous studies in the area. Although the climate data suggests an average summer in terms of temperature and rainfall, the precipitation episodes were often violent and short-lived, followed by periods of high heat. This dynamic climatic pattern is ideal for rapid decomposition. This rapid decomposition, coupled with voracious scavenger activity, make eastern North Carolina an ideal environment for rapid skeletonization. It is critical to note that control specimens present a biased and unrealistic estimation of PMI, as it is the exception to find remains from a surface deposition that have not been scavenged. Studies such as this provide a more realistic decomposition timeline.

### *Future Research*

This research focused solely on scavenger activity, but as has been stated, there are numerous factors that influenced the estimation of PMI. All of these factors need to be more thoroughly explored, especially in eastern North Carolina. Future research could compare scavenger activity between the coastal plains and the mountains, utilizing the facilities at Western Carolina University or the University of Tennessee at Knoxville. With East Carolina University being in proximity to the coast, an interesting comparison could also be done to marine or coastal environment scavenger activity. Another comparison to this research could be to investigate the differences in scavenger activity and scattering between clothed and unclothed remains. Another critical test not quantified in this research that could be studied, is preferential treatment by scavengers of specific body parts or skeletal elements. Specifically in regards to the swamp location of Site 3, and the loss of remains in the mud, a similar study could be conducted and excavations could be used to investigate the depth and distribution of buried and submerged skeletal elements over time.

In the end there are so many variables that influence estimates of PMI that any further studies that attempt to isolate them will be critical to our understand of the complex processes of decomposition. This research is valuable to the forensic anthropology community for scientific purposes, aiding in our understanding of the interrelationships between various variables that influence surface deposition sites. It is also practically valuable to local law enforcement and medico-legal specialists in its ability to shed light on actual forensic cases involving surface deposition sites influenced by scavengers. Also the rapid decomposition of the control may help medico-legal specialists get a more fine-tuned understanding of local decomposition timelines for future cases.

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# Appendices

## Appendix A. Daily High and Low Temperatures (F)

| Date | Temp high | Temp low |
|---|---|---|
| 12-Jun | 89 | 69 |
| 13-Jun | 96 | 69 |
| 14-Jun | 80 | 60 |
| 15-Jun | 86 | 60 |
| 16-Jun | 87 | 64 |
| 17-Jun | 87 | 69 |
| 18-Jun | 86 | 69 |
| 19-Jun | 80 | 68 |
| 20-Jun | 82 | 62 |
| 21-Jun | 84 | 55 |
| 22-Jun | 80 | 69 |
| 23-Jun | 87 | 71 |
| 24-Jun | 86 | 71 |
| 25-Jun | 89 | 69 |
| 26-Jun | 89 | 71 |
| 27-Jun | 91 | 69 |
| 28-Jun | 89 | 69 |
| 29-Jun | 86 | 69 |
| 30-Jun | 82 | 71 |
| 1-Jul | 80 | 71 |
| 2-Jul | 87 | 71 |
| 3-Jul | 86 | 73 |
| 4-Jul | 89 | 73 |
| 5-Jul | 89 | 71 |
| 6-Jul | 89 | 69 |
| 7-Jul | 89 | 71 |
| 8-Jul | 87 | 73 |
| 9-Jul | 89 | 71 |
| 10-Jul | 89 | 73 |
| 11-Jul | 87 | 71 |
| 12-Jul | 75 | 71 |
| 13-Jul | 87 | 71 |
| 14-Jul | 89 | 69 |
| 15-Jul | 91 | 69 |
| 16-Jul | 93 | 71 |
| 17-Jul | 91 | 69 |

| | | |
|---|---|---|
| 18-Jul | 93 | 73 |
| 19-Jul | 89 | 75 |
| 20-Jul | 89 | 75 |
| 21-Jul | 89 | 73 |
| 22-Jul | 89 | 75 |
| 23-Jul | 89 | 75 |
| 24-Jul | 91 | 69 |
| 25-Jul | 82 | 69 |
| 26-Jul | 86 | 64 |
| 27-Jul | 87 | 66 |
| 28-Jul | 87 | 73 |
| 29-Jul | 87 | 73 |
| 30-Jul | 86 | 71 |
| 31-Jul | 86 | 69 |
| 1-Aug | 82 | 73 |
| 2-Aug | 89 | 73 |
| 3-Aug | 89 | 75 |
| 4-Aug | 82 | 64 |
| 5-Aug | 86 | 60 |
| 6-Aug | 86 | 68 |
| 7-Aug | 87 | 66 |
| 8-Aug | 89 | 71 |
| 9-Aug | 91 | 77 |
| 10-Aug | 95 | 73 |
| 11-Aug | 91 | 71 |
| 12-Aug | 93 | 73 |
| 13-Aug | 91 | 73 |
| 14-Aug | 77 | 62 |
| 15-Aug | 77 | 59 |
| 16-Aug | 73 | 64 |
| 17-Aug | 80 | 64 |
| 18-Aug | 86 | 69 |
| 19-Aug | 77 | 66 |
| 20-Aug | 84 | 69 |
| 21-Aug | 87 | 71 |
| 22-Aug | 87 | 69 |
| 23-Aug | 89 | 69 |
| 24-Aug | 82 | 64 |
| 25-Aug | 80 | 59 |
| 26-Aug | 82 | 51 |
| 27-Aug | 87 | 62 |
| 28-Aug | 86 | 69 |

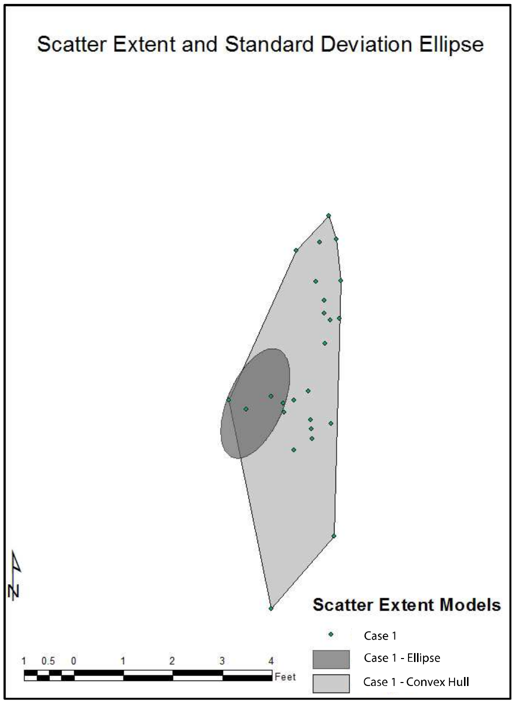
| | | |
|---|---|---|
| 29-Aug | 86 | 69 |
| 30-Aug | 87 | 62 |
| 31-Aug | 89 | 66 |
| 1-Sep | 89 | 71 |
| 2-Sep | 89 | 71 |
| 3-Sep | 87 | 68 |
| 4-Sep | 86 | 68 |
| 5-Sep | 87 | 66 |
| 6-Sep | 84 | 64 |
| 7-Sep | 80 | 55 |
| 8-Sep | 87 | 62 |
| 9-Sep | 87 | 62 |
| 10-Sep | 89 | 64 |
| 11-Sep | 89 | 64 |
| 12-Sep | 87 | 68 |
| 13-Sep | 86 | 68 |
| 14-Sep | 77 | 59 |
| 15-Sep | 80 | 51 |
| 16-Sep | 86 | 60 |
| 17-Sep | 77 | 55 |
| 18-Sep | 77 | 48 |
| 19-Sep | 77 | 50 |
| 20-Sep | 78 | 59 |
| 21-Sep | 77 | 60 |
| 22-Sep | 71 | 60 |
| 23-Sep | 71 | 53 |
| 24-Sep | 73 | 50 |
| 25-Sep | 73 | 50 |
| 26-Sep | 78 | 53 |
| 27-Sep | 75 | 55 |
| 28-Sep | 77 | 53 |
| 29-Sep | 77 | 55 |
| 30-Sep | 77 | 51 |
| 1-Oct | 80 | 48 |
| 2-Oct | 86 | 59 |
| 3-Oct | 86 | 59 |
| 4-Oct | 86 | 64 |
| 5-Oct | 89 | 64 |
| 6-Oct | 84 | 62 |
| 7-Oct | 84 | 69 |
| 8-Oct | 69 | 55 |
| 9-Oct | 62 | 55 |

| | | |
|---|---|---|
| 10-Oct | 60 | 57 |
| 11-Oct | 64 | 59 |
| 12-Oct | 69 | 60 |
| 13-Oct | 75 | 64 |
| 14-Oct | 71 | 59 |
| 15-Oct | 68 | 55 |
| 16-Oct | 73 | 60 |
| 17-Oct | 78 | 57 |
| 18-Oct | 69 | 60 |
| 19-Oct | 73 | 60 |
| 20-Oct | 66 | 44 |
| 21-Oct | 68 | 37 |
| 22-Oct | 62 | 51 |
| 23-Oct | 69 | 50 |
| 24-Oct | 59 | 39 |
| 25-Oct | 55 | 33 |
| 26-Oct | 62 | 32 |
| 27-Oct | 68 | 41 |
| 28-Oct | 69 | 42 |
| 29-Oct | 73 | 48 |
| 30-Oct | 73 | 46 |
| 31-Oct | 77 | 53 |

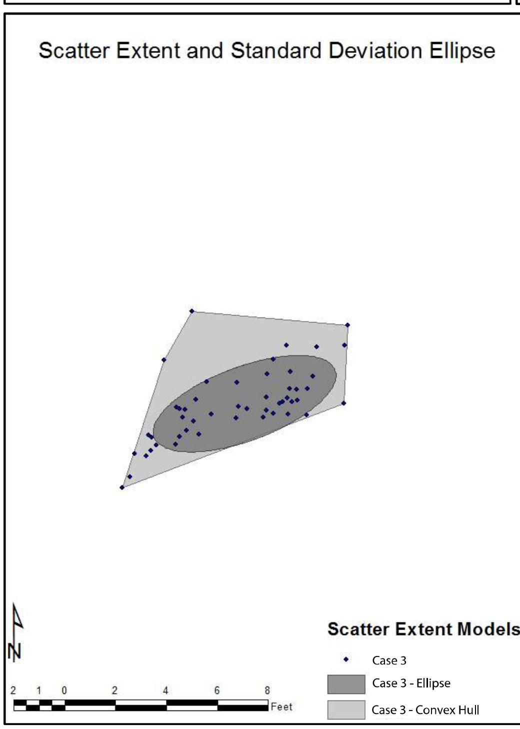
**Appendix B. Monthly rainfall amounts**

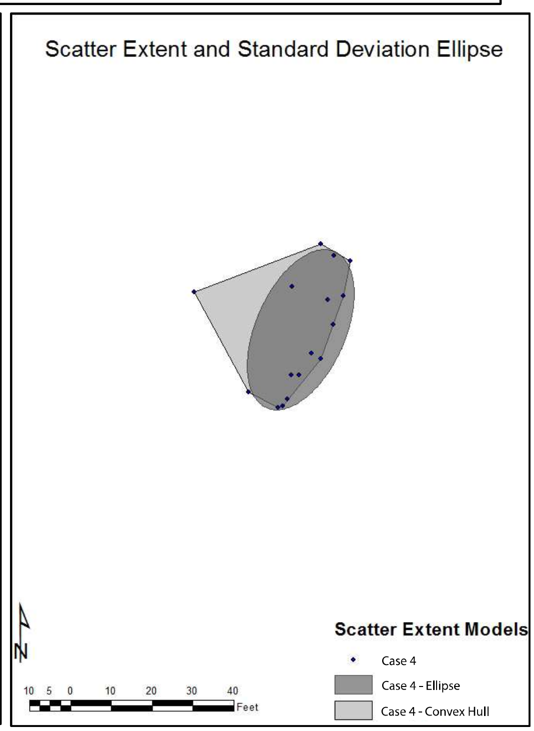
| Month | Precip (inches) |
|---|---|
| June | 4.15 |
| July | 6.74 |
| August | 0.15 |
| September | 5.5 |
| October | 2.2 |

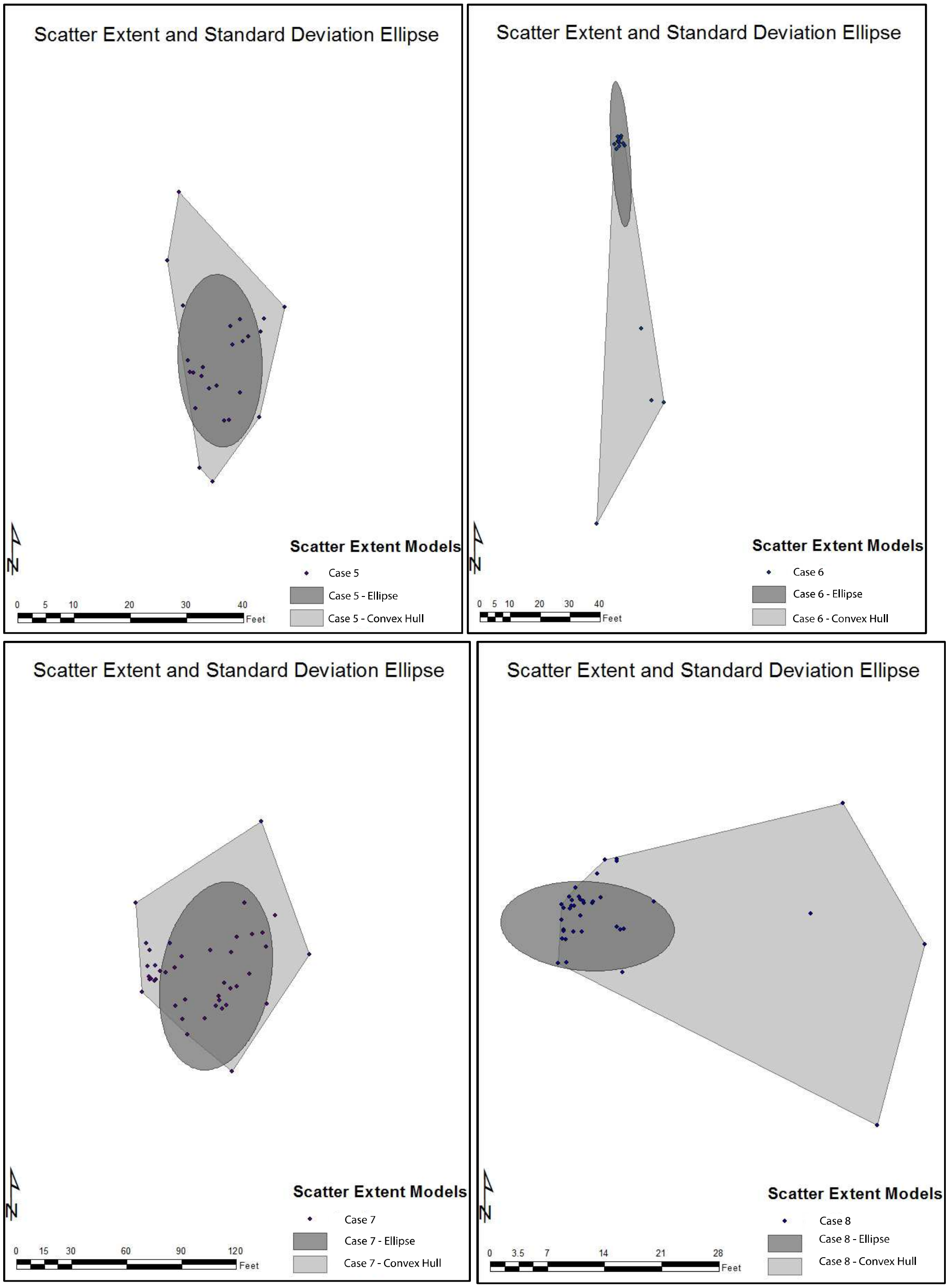
# Appendix C. Cases 1-12 Scatter Extent Maps

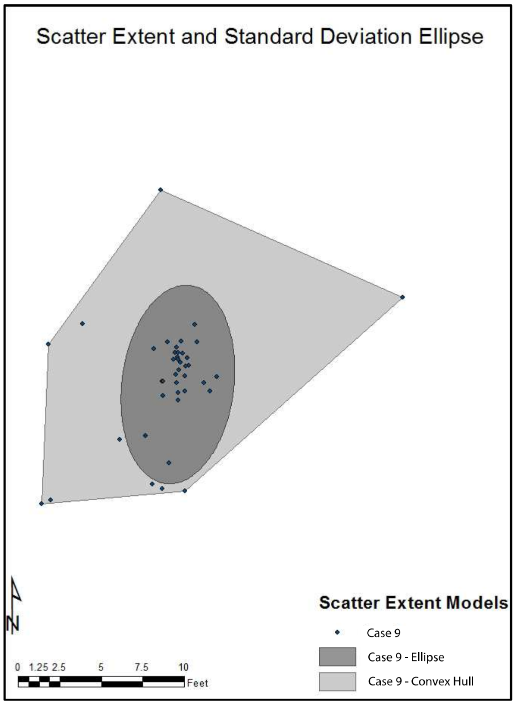


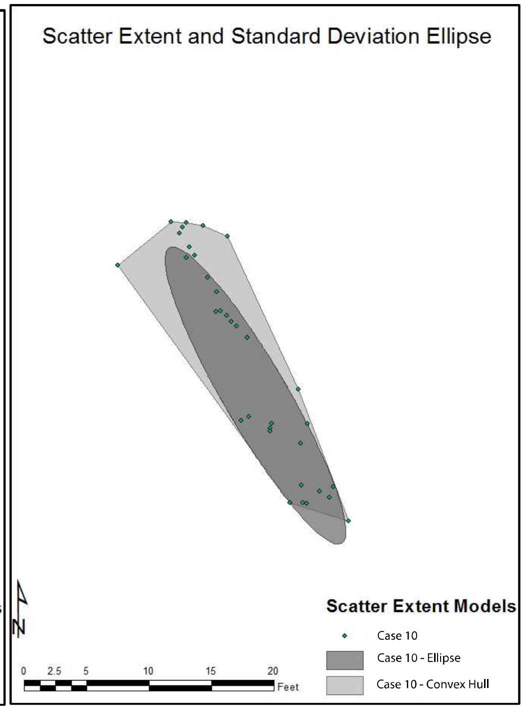


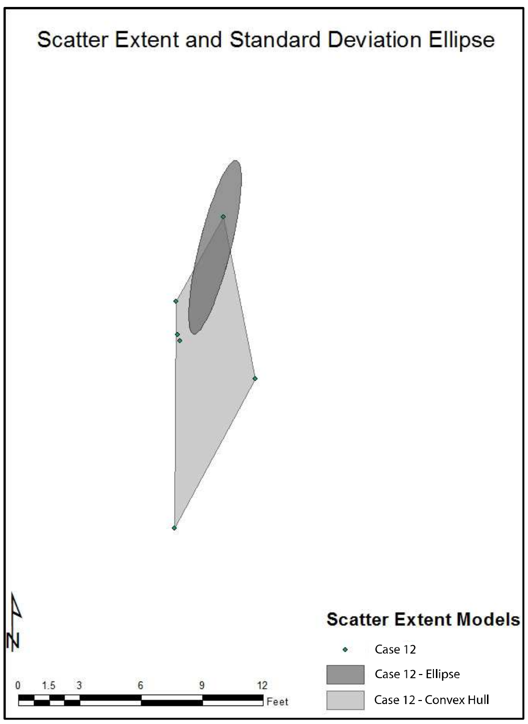


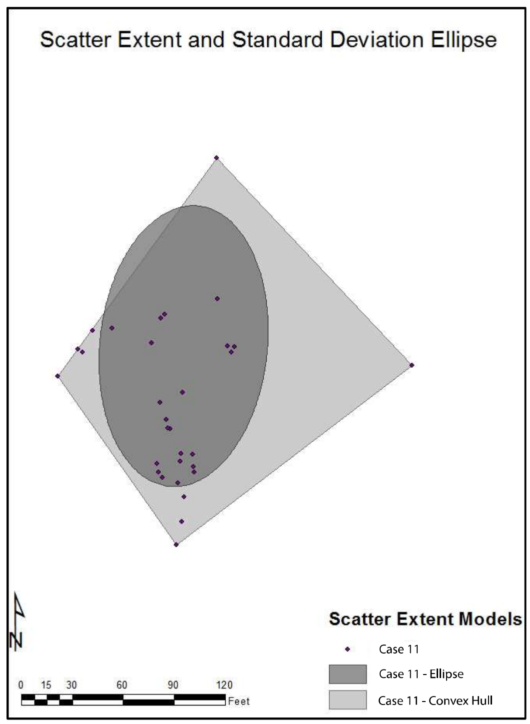




Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 5
Case 5 - Ellipse
Case 5 - Convex Hull
0 5 10 20 30 40 Feet
Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 6
Case 6 - Ellipse
Case 6 - Convex Hull
0 5 10 20 30 40 Feet
Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 7
Case 7 - Ellipse
Case 7 - Convex Hull
0 15 30 60 90 120 Feet
Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 8
Case 8 - Ellipse
Case 8 - Convex Hull
0 3.5 7 14 21 28 Feet


Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 9
Case 9 - Ellipse
Case 9 - Convex Hull
0 1.25 2.5 5 7.5 10
Feet


Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 10
Case 10 - Ellipse
Case 10 - Convex Hull
0 2.5 5 10 15 20
Feet


Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 12
Case 12 - Ellipse
Case 12 - Convex Hull
0 1.5 3 6 9 12
Feet


Scatter Extent and Standard Deviation Ellipse
Scatter Extent Models
Case 11
Case 11 - Ellipse
Case 11 - Convex Hull
0 15 30 60 90 120
Feet